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# Field and Laboratory Studies on the Development and Control of Soil Water Repellency of Sand Root Zone Mixes

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# FIELD AND LABORATORY STUDIES ON THE DEVELOPMENT AND CONTROL OF SOIL WATER REPELLENCY OF SAND ROOT ZONE MIXES

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FIELD AND LABORATORY STUDIES ON THE DEVELOPMENT AND CONTROL OF SOIL WATER REPELLENCY OF SAND ROOT ZONE MIXES

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## DEDICATION

To my mother, Donna Elmore, my sister, Emilee Elmore Mosier, and my two nephews, Ryan and Dustin Mosier I would like to say thank you for your many years of support and prayers in my educational endeavors but also in my life. Emmy… if I can do it, so CAN YOU. Without all of you none of this would have been possible. I love and cherish each of you more than you'll ever know. To LaVette Burnette for her selflessness and dedication not only to our friendship but to my education as well… thank you. Finally, I would like to say "thank you" to my father, Malcome Elmore. My father was my biggest fan and my best friend… I love you always Daddy, and I'll never forget all of our times together.

For Daddy

# TABLE OF CONTENTS

## LIST OF TABLES

## List of Figures

## ABSTRACT

Localized dry spots (LDS) associated with water repellent (i.e., hydrophobic) soils have detrimental effects on the survival, playability, and aesthetic value of creeping bentgrass (*Agrostis palustris*) used for golf course putting greens. The development of water-repellent soils, using molarity of ethanol water droplet tests to determine soil hydrophobicity, wetting agent evaluations, and water retention based on percent organic matter were investigated. Greenhouse, field, and laboratory studies were conducted at Western Kentucky University beginning in 2000 and ending in 2001. The greenhouse study was initiated to investigate the type of soil most capable of producing a hydrophobic condition. Using hydrophilic sand as a base, excised bentgrass roots, organic matter, and humate materials were incorporated into containers with live bentgrass turf. The field study, originally developed in 2000 to evaluate rates of Naiad wetting agent applied to established LDS due to hydrophobic soil, was modified to include Primer wetting agent in 2001. This study also compared the efficiency of MED testing based on soil sample size. Soil samples taken using a .63 cm in diameter soil probe were found not to differ from those measuring 1.27 cm in diameter. The laboratory study was designed to incorporate both hydrophilic and hydrophobic soil treatments, which were harvested from an experimental green. Both soils had differing amounts of organic matter, a Michigan peat moss, mixed in based on volumetric and weight calculations. Primer wetting agent was applied to half of the replicates from each soil type and weighed daily. Upon averaging the daily weights of the replicates within each treatment mix, those replicated receiving Primer

wetting agent did not hold significantly more moisture when compared to those that did not receive applications. Furthermore, the hydrophobic soil did not differ in moisture retention whether receiving the wetting agent or not. There were significant differences in the amount of moisture held in the differing amounts of organic matter; however, this did not occur across soil type. The treatments containing 20% organic matter by weight held significantly more water in comparison to the other treatments. The same was true in both the hydrophobic and hydrophilic soils. The results of this particular study suggest that wetting agents do not cause construction mixes to retain excess water when containing differing amounts of organic matter.

# Chapter One: Introduction

The habitual occurrence of localized dry spots (LDS) on sand-based putting greens has been attributed to soil compaction, improper chemical application, elevated terrain, poor irrigation coverage, excessive thatch buildup, and hydrophobic soils. Aerification, wetting agent applications, and deep, infrequent irrigation routines have been used to control LDS caused by these factors. However, hydrophobic or water-repellent soils remain difficult to control and eradicate. Hydrophobicity refers to the relative nonwettability of water on coarse sand particles (particle size 0.5 to 2.0 mm) which are susceptible to the rapid development of water repellency due to wax-like, organic particle coatings (Karnok and Beall, 1995).

The natural phenomenon of water repellency has a detrimental effect on creeping bentgrass (*Agrostis palustris*) putting greens. Unable to penetrate the soil, the water runs off or moves through the soil pore space without wetting the soil particles. Due to a lack of moisture, irregular, blue-green or blue-purple patches of turf appear as the early stages of LDS. Rapid tissue desiccation continues as these abnormal patches of turf drop below a critical soil moisture content. Not only is the aesthetic value of the golf course affected, but also the playability of the surface deteriorates significantly. Patches of LDS affected turf can be lost within hours during a hot, dry summer day. Therefore, golf course maintenance crews spend valuable time and resources to temporarily alleviate the symptoms of LDS caused by hydrophobic soils.

For decades researchers have examined hydrophobic soil occurrences; however, gaps remain in the developmental phase of water repellent soils. Furthermore, vegetation amounts, species, soil textures and types, and certain soil fungi may play important roles. Nonetheless, many causes continue to evade discovery while cures elude turfgrass managers. The objectives of this study were as follows:

1) To determine the effect of vegetation and organic matter on hydrophobic soil development.
2) To evaluate the performance of wetting agents on an established LDS caused by hydrophobic soil and to evaluate soil-sampling methods when measuring soil hydrophobicity.
3) To determine the effect of organic matter on water retention in both a hydrophobic and hydrophilic sandy soil in the presence of a wetting agent.

## Chapter Two: Literature Review

Hydrophobic soils, a problematic soil condition, affect all entities of agriculture, such as land and pasture management, forest preservation, citrus groves, as well as golf courses. This literature review provides a chronological overview of hydrophobic or water repellent soil research that began in the early 1900's.

In the 1930's and 40's, hydrophobic soils were investigated under declining citrus trees in Central Florida, while other investigators examined recently charred forests and grazed pastures throughout California and Australia. While earlier researchers anticipated a relationship between drip lines surrounding citrus trees and hydrophobic soil, others isolated metallic soaps derived from fatty acid decay, which coated the soil particles rendering them water repellent. LDS caused by hydrophobic soils were observed on golf greens during the 1960's and 70's.

Jamison (1939) attempted to discern the cause(s) of citrus tree decline in central Florida by studying the drip line area beneath the trees. Jamison expected to note a relationship between the dry soil surrounding the trees within the drip lines and rainfall amounts. However, Jamison quickly noticed dry and water repellent soil within the area, which lead him to investigate the chemical and physical characteristics of the soil. The evaluation of pesticide applications was expected to find oil-based chemicals as the cause of water repellency; however, Jamison ruled out that possibility after careful analysis and years of observation (Jamison, 1945). Nonetheless, Jamison (1945) did determine that amending sandy soils with clays did reduce the severity of the hydrophobicity.

In other parts of Florida, Wander (1949) evaluated fertilizer products, expecting to observe hydrophobic properties in the soil. Consequently, Wander's evaluation found that fatty acid degradation produced Ca and Mg metallic soaps, which were significantly hydrophobic. Wander's research failed to identify the fatty acids responsible for the organic coatings on soil particles, just as Van't Woudt (1959) attempted to prove that increasing contact angles yielded decreasing soil wettability. Van't Woudt examined volcanic ash under native vegetation and coniferous trees marking a hydrophobic condition in the soil. Subsequently, Van't Woudt extracted cholesterol and fatty acids from these soils, without identifying the origin of the waxy substances.

To further develop Van't Woudt's efforts in identifying the origin of waxy substances, Bond (1964) hypothesized that plant species, age of the soil and management practices contributed to hydrophobic soil development caused by waxy substances. Examining the pastures of southern Australia, Bond reported that the severity of soil water repellency varied due to vegetative cover. Bond also acknowledged the influence of basidiomycete fungi growing under various plant species. Bond found abundant mycellial growth within decaying root material of the top 18 inches of soil, existing in the water-repellent area. Bond suggested that with time, water repellency increased; however, the time of significance was indistinguishable. Bond related the development of the hydrophobic soil to basidiomycete fungi responsible for fairy ring. However, organic matter degradation by microorganisms was only speculation and required further examination.

Watson and Letey (1970) established a measurement of hydrophobicity by introducing aqueous ethanol solutions. By studying contact angles and capillary rise, Watson and Letey observed the time for droplet penetration of these solutions on soil cores and discovered a relationship to surface tension. The researchers developed the MED or molarity of ethanol droplet method that produced the same data as the capillary rise method used previously to determine the severity of water repellency of a soil. The persistence of the delivered droplet or the amount of time taken for a drop to penetrate the soil increased with higher levels of hydrophobicity. Watson and Letey hypothesized that soils with "persistence" would present more difficulty in reducing the contact angle below $90^0$ C.

Debano (1971) investigated the effects of hydrophobic soil caused by fire scorched forest soils and grasslands. The research focused on the effects of hydrophobic substances on water movement within the soil. Through a process of horizontal and vertical infiltration, DeBano observed a sharp decrease in water content between a hydrophobic and hydrophilic soil. At low soil moisture content, DeBano recognized a significant effect of hydrophobic substance on water movement and retention. Conversely, he witnessed the same affect in reverse on high moisture content soils; leading him to suggest a critical soil moisture content was responsible for the severity of water repellent soils.

Miller and Wilkinson (1977) extracted hydrophobic sand grains from a golf green suffering from LDS. A scanning electron microscope (SEM) enabled the researchers to view a particle coating on sand grains from the affected area, but not from wettable areas. Removal of the coating revealed organic matter from Ca and Mg salts of fatty acids. Ultimately, the substance was found to be a fulvic acid coating formed by Ca and Mg fulvate. Upon dehydration, this substance increased in hydrophobicity. Miller and Wilkinson could not establish a relationship between basidiomycete fungi and the organic coatings; however, they speculated that microorganisms produced these coating following microbial synthesis of the decaying fungi.

Wilkinson and Miller (1977) studied LDS on sand based golf greens. Attempting to "cure" the hydrophobic condition on golf greens, Miller and Wilkinson applied Hydro-Wet and Aqua-Gro wetting agents to the affected area. From their observation that the water-repellent condition was limited to the top 2 cm of soil, the researchers concluded that coring would temporarily alleviate the dry spots, while a combination of aerification and wetting agent applications was deemed beneficial. They also showed that wetting and drying cycles contributed the LDS severity and increased the degree of hydrophobicity. Miller and Wilkinson concluded that myceliel growth did facilitate the development of organic coating.

King (1981), while examining the soils of Australia, attributed water repellent soils to fungal hyphae, humic acids, and decomposing plant material. In efforts to predict soil-water contact angles, soil temperature, soil abrasion and soil moisture content were evaluated to determine their effects on testing for soil water repellency. King found that MED and WDPT (Water Droplet Penetration Test) were not significantly different, but variability in repellency did exist in sieved and unsieved soil samples. Variability in soil repellency was associated with the presence of organic matter and roots, hence light sieving was suggested. The abrasion of the particles reduced repellency significantly thus organic coatings were abraded from sand particles. King also revealed that temperatures above $45^0$ C greatly affected MED test results, suggesting that optimum testing temperature ranged between 0 and $36^0$C. King failed to demonstrate a relationship between MED sampling techniques to the amount of soil tested.

Demonstrating that hydrophobic soils were a global issue, Nakaya (1982) observed water repellent soils in Japan. Discussing new aspects of organic matter effects on water repellency, Nakaya evaluated both hydrophobic and hydrophilic soils and the effect of wetting resistance on water movement in moist soil. Utilizing capillary rise, Nakaya concluded that air trapped in organic matter disrupts water infiltration and that regardless of drying or wetting organic matter does not directly cause hydrophobic or hydrophilic soil. Nakaya observed that organic matter formed wetting fronts in the soils and rendered sand water repellent.

Further research into water penetration into soils differing in textures and initial moisture content revealed significant information. Malik et al. (1987) measured water penetration and initial moisture contents of sandy soils, clays and loams using capillary rise action. The researchers found that sandy soils lost more moisture than did clays and loams over time, while initial water content were comparable. The comparison signified the importance of initial water contents on future wetting processes. As the hydrophobic sand dried, it became increasingly more difficult to rewet in future attempts when compared to finer textured soils. Malik et al. attributed this to soil water contact angles.

In the 1980's, the use of nonionic surfactants, or wetting agents, increased due to the frequent occurrence of LDS. Many studies were conducted to test the effects of wetting agents on hydrophobic soils. Nevertheless, their effects on hydrophilic soils were unknown. Carrow (1989) described nonionic surfactants in the following manner:

1. Anionic- negatively charged, phytotoxic, easily leached, short residual effect and wets quickly.

2. Cationic- positively charged, tightly bonded to the soil, slightly phytotoxic, slow to wet.

3. Nonionic- neutrally charged, persists in soil, least phytotoxic.

Of these three types, Carrow (1989) concentrated on nonionic wetting agent use on golf courses due to low phytotoxicity and its residual effects. Attempting to estimate the effect of nonionic wetting agents on hydrophilic soils, Carrow (1989) stated that wetting agents react negatively, due to chemical reactions, in wettable soils. Wetting agents are limited in efficacy in hydrophilic soils due to limited influence on capillary force, which lowers infiltration rates. Furthermore, Carrow (1989) noted that wetting agents facilitated drainage in hydrophilic soils due to decreased surface tension. Carrow also stated that wetting agents positively influence water retention in water-repellent soils. Carrow suggested that the waxy, organic coating was not "washed off" by wetting agents but was covered by the wetting agent allowing water to be retained. Furthermore, the contact angle was lowered on the particle surface allowing the beaded water to penetrate porous surfaces (Carrow, 1989).

Attempting to alleviate water repellency through the use of soil amendments, Ma'shum et al., (1989) cited erosion and conservation as important issues in southern Australia. By intermixing fine particulates of dispersible clays with sand particles and observing their effects on water repellency, Ma'shum et al. (1989) determined that clays lowered soil water repellency. Though helpful, the process was inefficient for large areas but could be promising for the golf course industry.

Karnok and Tucker (1989) initiated experimental procedures designed to analyze the chemical and physical properties of hydrophobic soils. Using several treatments, such as Tide, a laundry detergent, and various wetting agents, Karnok and Tucker performed many lab and field trials to alleviate soil water repellency. Though wetting agents were found to reduce water repellency, the effects were temporary. Unable to "flush off" the organic coatings, Karnok and Tucker (1989) utilized hydrogen peroxide treatments to remove the coating, but field studies were inconsistent. Karnok (1989) suggested that wetting agents varied in efficacy on LDS by product due to formulation. Phytotoxicity was possible with high rates of some products tested. Ultimately, superintendents remained confused throughout the 1980's on the use and efficacy of wetting agents.

Tucker et al. (1990) studied management practices on golf greens by comparing physical properties of healthy turf with those exhibiting LDS. Utilizing the WDPT, hydrophobicity, contact angles, soluble salts, organic matter content, moisture content and particle size were measured and statistically evaluated for relationships. As a result, no relationship was established between management practices on LDS severity; however, Tucker et al. detected differences in WDPT and contact angle in healthy areas compared to adjacent LDS on putting greens. Organic matter coatings coincided with previous observations using a SEM (Scanning Electron Microscope), and the condition persisted only in the top 2 inches of soil. Neither particle size nor chemical property analysis yielded any further answers.

Bisdom et al. (1993) studied soil biota extensively in the Netherlands. Upon examination, microaggregates created by organic matter breakdown induced water repellency along with rounded, macro-aggregates and coated plant remains. The researchers suggested that field and lab experiments would establish the exact role of soil biota in soil structure formation, and organic matter decomposition was necessary to obtain an accurate relationship. In conclusion, the researchers found a strong relationship between organic matter from plant remains, with and without coatings created water-repellent soil.

Karnok et al. (1993) attempted to wash off organic particle coatings on hydrophobic soil with high pH treatments. Across seasonal studies, Karnok et al. (1993) showed NaOH applied to hydrophobic soil on bentgrass putting greens significantly lowered water repellency. The high pH treatments solubilized the hydrophobic coating, thus increasing soil wettability. High air temperatures and the number of applications caused turf injury.

Hudson et al. (1994) pursued other avenues of LDS research. The extraction of lipids and alkaline extracts from LDS due to hydrophobic soil yielded no new qualitative differences between LDS and healthy patches of turf. The extraction of organic materials proved that humic-like acids were responsible for soil particle composition. Unlike Hudson et al., Franco et al. (1995) attributed intrinsic particulate organic matter to the development of water repellency by carrying waxes from plant sources. Due to physical interaction, Franco et al. (1995) substantiated the claim that coated sand particles determine the degree of hydrophobicity. Furthermore, the researchers concluded that native vegetation was the originator of water repellency.

In an evaluation of LDS due to water repellent soils, Karnok and Beall (1995) stated that a 100% sand root zone would eventually develop a hydrophobic condition within six to 18 months following construction. Karnok and Beall (1995) revealed that a (85/15) sand/peat root zone mix was most susceptible to LDS development when compared to a 90/10 mix or 100% sand mixture. Instead of evaluating green construction mixes, Dekker et al. (1998) illustrated that a soil is water repellent below and wettable above a critical water content. However this content was variable and considered impossible to predict. Due to decreasing water absorption by soil samples, high drying temperatures increased water repellency in micromorphological analyses. Dekker et al. (1998) attributed the increase in repellency to the formation of organic carbon coatings.

De Jonge et al. (1999) found that small soil size fractions were more hydrophobic than larger soil samples when tested. Hence, water repellency may have been wrongly classified due to soil sample sizes, which were inadequate representations of the affected area. A standard size soil sample was necessary for accurate MED and WDPT methods of measurement.

In recent years, wetting agent use, aerification, microbial degradation, fungal hyphae, soil compaction, pesticide and fertilizer usage have been targeted for research. Karnok and Tucker (2000) have suggested further study concerning the influence of thatch/mat on wetting agent efficacy. Doerr et al. (2000) elaborated on exigent hydrophobic soil research by stating that critical soil moisture contents were important variables that have yet to be clearly understood.

## Chapter Three: MATERIALS AND METHODS

### Study I: Determination of vegetation and thatch buildup on hydrophobic soil development

In June 2000, a greenhouse study was initiated at Western Kentucky University, Bowling Green, Kentucky, on the development of hydrophobic soils. The study was a simulation of root zone mixes typically found in putting green construction. A 3.8 l nursery pot was used for each of the four treatment mixes, which were replicated four times each. The treatments were as follows:

1. Live, excised bentgrass roots. (Figure 1)
2. Organic matter. (Figure 2)
3. Humate material. (Figure 3)
4. Pure non-hydrophobic topdressing sand.

Each of these treatments had four replications with and without live creeping bentgrass turf, which was sodded on top of the treatment mix (Fig. 4). The topdressing sand used at the Western Kentucky University farm had no hydrophobic characteristics as determined by the Molarity of Ethanol Droplet (MED) test described by Watson and Letey (1970). The MED test used for this study consisted of the following: Samples were taken from the selected area and air-dried for 48-72 h. Each sample from the same plot was then combined. Using a mortar and pestle, the sample was crushed, not ground. The samples were then sifted and separated from the plant material. The sample was then placed in a container and a 40 μl droplet of an ethanol ($C_2H_5OH$) and distilled water solution was placed on the surface of the sample by using a pipette. The amount of time taken for the droplet to fully penetrate the sample determined the hydrophobicity of the soil. The higher the molarity of ethanol in the solution, the greater the degree of water-repellency. A scale of 1.0 to 4.0 is used to measure hydrophobicity, with 4.0 being severely hydrophobic. When a droplet does not penetrate the soil within 5 s, the next highest molarity of ethanol is applied. Each of the solutions was mixed with a graduated cylinder as shown in Table 2. The solutions were refrigerated in Nalgene, polyurethane bottles.

The sand was sifted through a #20 sifter (E.H. Sargent & Co.) to remove any large particles. The sand was burned in a Lindberg muffle furnace for 24 h at 475°C to determine the organic matter present. The test determined that the sand held 0.05% organic matter prior to mixing. The live, excised roots came from an experimental green at the Western Kentucky University Farm. 'Crenshaw' creeping bentgrass sod was removed from the green, the roots thoroughly washed with water to remove the existing soil, trimmed away from the plant crown with scissors, and rinsed once again with water. The roots were then air-dried in a laboratory at 21°C for 72 h. The weight of the roots typically found in the top 50.8 mm of soil was estimated at 10 g. The 10 g of the roots were ground in a Wiley Mill so that they would pass through a 40-mesh screen. No live turf was sodded on the pots with excised roots. The roots served as the plant residues which could to be necessary for the development of a hydrophobic situation. The organic matter, a Michigan peat, was sifted through a #20 sifter and ground in a Wiley Mill so that it would also pass through a 40-mesh screen. Humate International Inc. donated the humate material, which was also ground in a Wiley Mill so that it would pass through a 40-mesh screen. The humate material contained humic (Roberts and Carbon, 1972) and fulvic acids (Miller and Wilkinson,

1977) which have both been targeted by scientists as creating a water-repellent coating on soil particles (Figure 5).

Containers were filled with the topdressing sand, leaving 50.8 mm of space to add the treatments. Each of the treatments were then combined with the sand by hand in plastic containers and poured to a depth of 50.8 mm on top of the topdressing sand (Figure 6). Each container had a rate of 48 kg N/ha or 454 g of IBDU (isobutylidine diurea) fertilizer incorporated into the top 50.8 mm.

The pots were first placed in a laboratory at 20°C air temperature for two months so that the live turf replications could begin to root into the treatment mixes. A 1000-watt, metal halide grow lamp was placed .912 m above the pots and set on a timer for 14 h per day for six days (Figure 7). The pots were then randomized two times per week, watered when necessary and treated with 11.36 g Heritage (*Azoxystrobin*) as a preventative fungicide. The pots were monitored daily for disease presence, trimmed with hand scissors two to three times per week, and maintained at a height of 6.35 mm. All treatments received the fertilizer, irrigation and pesticide applications as recommended. The pots received water only when necessary to prevent turfgrass loss and to increase the possibility of developing soil hydrophobicity.

On September 8, 2000 the containers were transported to a greenhouse at the Western Kentucky University farm where they were maintained for 13 months. Nitrogen was applied to the pots at 24.5 kg/ha every four months. Daconil 2787 (Chlorothalonil) and Heritage were used as preventative fungicides throughout the maintenance period. The average daily temperature ranged from 20°C in the fall and winter months to 40°C in the summer months. Hydrophobic situations occur during heat and drought stress, so the pots were allowed to undergo these physiological stresses throughout the year (Karnok et al., 1993). The metal halide lamp was utilized in the fall and winter months when the hours of daylight fell below 10 h. No tests were performed on any of the replications during this maintenance stage, only common maintenance practices.

Each treatment was replicated four times in a randomized complete block design. The analysis of variance of the data was conducted by using the Anova procedure in SAS, and using Duncan Multiple Range tests (SAS, Version 8, SAS Institute, Cary, North Carolina) separated the means. The significant differences were tested at the $\alpha = 0.05$ level.

**Study II: Wetting agent performance on established LDS and soil sampling methodology.**

To compare two wetting agents and their ability to retain moisture in a hydrophobic situation, a field study was conducted at the Western Kentucky University Farm on an experimental green. University students, as a class project, constructed the experimental green in 1995 (Figure 8). The cultivar selected was 'Crenshaw' creeping bentgrass, which developed a severe, localized dry spot several years prior to the study. The area habitually showed drought stress symptoms from a lack of soil moisture (Figure 9). On May 25, 2000, fifty-two plots were designated and measured at 0.6 m by 0.6 m. To determine the hydrophobicity of the plots, the MED as described in Study I (Wilkinson and Letey, 1970) was utilized, and sixteen plots were found to range from 2.4 – 2.8 on the scale of hydrophobicity (Figure 10).

The scale begins at 0.0, as hydrophilic and ranges to 4.0 as most severely hydrophobic. The plots chosen for study were moderately hydrophobic.

A $CO_2$ sprayer obtained from BellSpray Inc. was used to deliver the wetting agents onto the desired plots (Figure 11).

1. Four plots received 7.2 ml of Naiad wetting agent monthly over four months from May to August 2000 (Fig. 12).
2. Four plots received 3.6 ml of Naiad wetting agent per application for the same four months.
3. Four plots received 7.2 ml of Naiad wetting agent in one application in May 2000.
4. Four other plots received no application and were observed as controls.

Immediately following each application, the plots received 12.7 mm of irrigation water to wash the material into direct contact with the soil, immediately following each application. Exactly one month following the first application, each of the plots was sampled 5 times with a 13 mm diameter by 25.4 mm deep probe (Figure 13). The samples were taken to a laboratory, air dried for 48 h and MED readings were taken and recorded for each plot.

In November 2000, the final samples of the season were collected and the final MED readings recorded. A randomized block design was utilized to analysis the data. The four replications were statistically analyzed using the ANOVA, described in Study I. No significant differences were found at the alpha 0.05 level. Because no differences were discovered, Study II was modified in 2001 in the following manner. In May 2001, the same 13 mm diameter by 25.4 mm deep probe listed above was used to select 5 samples from the experimental plots to determine initial MED readings. From these same plots, a hand-made, 6.35 mm diameter by 12.7 mm deep soil probe was used to pull 10 cores (Figure 14). Twelve plots were selected based upon the similarity between sampling method relative to MED readings. To compare the efficacy of two wetting agents on water retention within LDS, Primer wetting agent and Naiad wetting agent were applied. The treatments sampled 5 times using a 12.7 mm diameter probe were tested using approximately 5.00 cm of soil, whereas the 6.35 mm diameter probe tested 10 samples at 10.00 cm of soil. For this reason, the sampling methodology could then be tested and analyzed for consistency using both sampling methods as described above. Considering that the 6.35 mm diameter samples tested more soil, the MED readings from these treatments were thought to be more representative of the overall hydrophobicity of the plot. On May 11, 2001, a portion of 3.79 ml of Naiad wetting agent were applied to four treatments using the earlier described $CO_2$ sprayer, while a portion of 2.84 ml of Primer wetting agent was applied to four treatments (Fig. 15). Four treatments were maintained as control replications and received no application. Again, the treatments received 12.7 mm of irrigation water to flush the material into the soil. One week following this application, the treatments were sampled in the above manner. The samples were air dried in the laboratory for 48 h and tested using the MED method. Thirty days following the initial application, the treatments were sampled once again and treated in the same manner.

The second and final applications came on June 15, 2001. The Naiad treatments received the same amount of wetting agent previously described; however, the Primer treatments received 1.89 ml of wetting agent, as recommended on the label. The treatments were again irrigated with 12.7mm of water. No samples were taken in week one, but were collected and tested using the MED method exactly one month following the final application. The experimental green had no aerification in 2000 on the experimental plots; however, it was aerified in April 2001and lightly topdressed with the hydrophilic sand described in Study I. The green was maintained at a 3.175mm cutting height and fertilized with 10.75 N/ha in the spring and 10.5 N/ha with 16-16-16 in the fall of 2000. In spring 2001 the green was fertilized with 10.75 N/ha with an analysis of 16-16-16 and 20.5 N/ha in the fall.

The randomized complete block design was analyzed using the ANOVA listed in Study I. The wetting agent treatment means were separated using DMR. Significant differences were those occurring at the $\alpha = 0.05$ level. The sampling methodology was tested using a completely randomized design, and the treatment means were separated using LSD. Those differences also occurred at the $\alpha = 0.05$ level.

**Study III: Laboratory determination of water retention due to organic matter content within hydrophobic and hydrophilic sands in the presence of a wetting agent.**

A third study to investigate the water retention of putting green construction mixes was conducted in the turfgrass laboratory in the Department of Agriculture at Western Kentucky University. On January 15, 2001, the study involving 8 treatments was initiated. The purpose of the study was to simulate green construction using 255.96 g clear, plastic Solo cups. To determine the effects of differing amounts of organic matter on water retention in both a hydrophilic and hydrophobic soil, cups first had 10 small holes punched around the base to allow for drainage and sub-irrigation. Next, pea gravel, obtained from the Western Kentucky Farm, was washed and placed in the bottom of each cup to a depth of 19.05 mm. The gravel ranged in size from 6.35-12.7 mm each. Two layers of cheesecloth were cut to the diameter of the cup and placed on the gravel, to prevent the soil from being flushed down into the gravel and out the drainage holes (Fig. 16). The respective treatments were then hand-mixed in plastic containers and poured into the cups with the aid of a small funnel (Fig. 17). Each cup held 31.75 mm of treatment mix in depth. This depth left 6.35 mm of space from the surface of the cup to the surface of the soil. The treatments were as follows:

1) hydrophobic soil – control (Fig. 18)
2) hydrophobic soil with 20% organic matter (by weight) (Fig. 19)
3) hydrophobic soil with 10% organic matter (by weight)
4) hydrophobic soil with 20% organic matter (by volume)

The hydrophobic soil was harvested from an experimental green at Western Kentucky University, tested using the MED method described in Study I and determined to be severely water-repellent at 3.4 on the scale of hydrophobicity. The soil was sifted through a #20 (E.H. Sargent & Co.) sifter and air-dried for 20 d in the laboratory at 30°C. The organic matter used in each treatment was a Michigan peat, purchased from a local landscape nursery, which was described in Study I. The peat was first passed through a #20 sifter, then ground in a Wiley Mill so that it would pass through a 40-mesh screen. Both volumetric and weight calculations were performed to simulate the construction methods commonly used in the transition zone. The hydrophobic soil was burned in a Lindberg muffle furnace at 475°C for 24 h to determine the organic matter content. The soil had 4% organic matter; thus the calculations of organic matter being added to the treatments had to be adjusted accordingly. The final four treatments consisted of the following:

1) hydrophilic sand with an organic matter content of 0.5% - control (Fig. 20)
2) hydrophilic sand with 20% organic matter (by weight) (Fig. 21)
3) hydrophilic sand with 10% organic matter (by weight)
4) hydrophilic sand with 20% organic matter (by volume)

The sand was also sifted with the same #20 sifter and air-dried for 20 d in the same laboratory. This sand is the same topdressing sand that was utilized in Study I to fill the containers.

After each treatment was poured into the cups, their weights were measured on an electronic scale and recorded (Fig. 22). At this point, each cup was placed into separate plastic dishes and sub-irrigated with water (Fig. 23). The sand treatments readily absorbed the water, whereas the hydrophobic treatments took 4 h to absorb the water. The hydrophobic treatments exhibited the fingered flow patterns or air pockets as described by Jamison in 1942 and were difficult to wet (Fig. 24). As this difficulty was expected, the hydrophobic soil was first stirred slowly in water prior to being poured into the cups to force the soil to wet. Each of the cups were brought to field capacity and allowed to drain for 15 m. At this point, exactly half of the treatments received Primer wetting agent at .02 ml. The wetting agent was applied with a spray bottle, which was calibrated prior to application (Fig. 25). The wetting agent was immediately flushed into contact with the soil with 12.7 mm of water applied directly to the surface using a Nalgene, squeeze bottle. All treatments were then brought to field capacity a second time, drained for 15 m and weighed and recorded.

Following this stage, each of the treatment cups were weighed daily for 12 d or until they fell below 10% moisture. On January 26, 2001, the second phase of the study began. Each cup was sub-irrigated in the same manner above and brought to field capacity. The hydrophobic treatments readily accepted the water because the cups had not fallen below the critical moisture point as described by Karnok and Tucker (1999). The cups were allowed to drain for 15 m and weighed on the same scale or accuracy. Again, the cups were weighed daily for 13 d, or the point at which they had fallen below 10% moisture.

The purpose of the two wetting and drying phases was to simulate field conditions. Wilkinson and Miller (1978) stated that wetting and drying phases actually increase the severity of the hydrophobic condition. Also, the effect of the wetting agent on water retention could be studied while in the presence of the differing amounts of organic matter. The study was performed in the laboratory at 21°C. A randomized complete block design was used, and the analysis was done through Proc ANOVA in SAS (Version 8, SAS Institute, Cary, North Carolina). Treatment means were separated using DMR. The significant differences were those tested at the $\alpha = 0.05$ level.

## Chapter Four: Results and Discussion

**Study I:**

Following thirteen months of maintenance, no significant hydrophobic development was observed in any treatment in Study I (Table 1). In August 2001, each of the replications was sampled and water repellency was measured using the MED method (Fig. 26). The lack of hydrophobic soil development may be explained by the amount of time necessary for a hydrophobic condition to develop. Karnok and Beall (1995) stated that 6 to eighteen months are necessary for soil water repellency to occur. Since the sand used to fill the pots was hydrophilic prior to initiation of study I, it is apparent that more time is necessary for a hydrophobic situation to occur within a greenhouse environment. Because the time frame allotted for the study did not produce a hydrophobic situation, other causes for a lack in water-repellent soil development can be further investigated. Because the containers with live turfgrass were maintained within a greenhouse, the temperatures often reached above $30^0$ C. For this reason, the containers were often watered to prevent turfgrass loss due to dehydration. It is apparent that the containers were not allowed to dry down past a critical soil moisture point discussed in Chapter Two, which resulted in a hydrophilic soil environment. The moisture level was maintained at or above a critical soil moisture point, below which the soil would have become water-repellent.

**Study II:**

On July 16, 2001 study II was terminated at Western Kentucky University's Farm. No significant differences were observed between treatment application rates in the 2000 season. Although three different rates of Naiad wetting agent were applied to the experimental plots, the hydrophobicity was not lowered during 2000. No phytotoxicity was observed on the creeping bentgrass in 2000. Each of the plots received visual NTEP ratings at or above 5.0. These ratings were based on the National Turfgrass Evaluation Program rating system. Due to variation within the sampling procedure, experimental error due to soil depth was a probable factor in the 2000 trials causing modifications to the study in 2001. Thus, in 2001, Primer and Naiad wetting agents were used as treatment applications. Furthermore, two sampling procedures, which are described in the Materials and Methods section, were used. No significant differences were found between sampling procedures; however, significant differences existed between the two wetting agents. The Primer wetting agent reduced the hydrophobicity of the plots following all three applications and remained effective for at least one month following each application. The Naiad wetting agent failed to significantly lower water repellency after all applications. No phytotoxicity was observed with either product. The LDS plots treated with Primer had significantly less turfgrass tissue desiccation and damage due LDS caused by soil hydrophobicity (Fig. 27). The control and Naiad plots had significant turfgrass loss due to LDS symptoms (Fig. 28).

In May and June of the 2001 season, the experimental green being tested in study II had a severe dollar spot (*Sclerotinia homeocarpa*) infestation, possibly due to a nitrogen deficiency (Fig. 29). Prior to treatment with Daconil 2787 (Chlorothalonil), Fore (Mancozeb), and Aliette (Fosetyl-al), it was noted that the plots treated with Primer had significantly less dollar spot than the other treatments, possibly due to the fact that these plots had more healthy turfgrass from the wetting agent application. No explanation was readily available; however, future investigation might reveal a correlation.

**Study III:**

Upon completion of two wetting and drying cycles, significant differences were observed between organic matter content in both the hydrophobic and non-hydrophobic soils being tested. While no differences were found between those treatments containing Primer wetting agent or the control replications, significant results between organic matter content on water retention were noticeable.

The treatments containing 80% organic matter by weight held significantly more water throughout the course of the study based on the ANOVA. Furthermore, the 10% organic matter by weight treatments held more water than the 20% organic matter by volume treatments, while the treatments having no additional organic matter held the least water of all treatments. This trend of increasing water-holding capacity with increasing organic matter content was repeated in both cycles. Interestingly, the same pattern was observed across both the hydrophobic and hydrophilic soils. There were no significant differences between the behavior of the two soils in the presence of the wetting agent.

## Chapter Five: Summary and Conclusions

1) MED tests confirmed no hydrophobic soil development over a period of 13 months in Study I (Table 1).

2) Visual evaluation of the live turfgrass replications revealed that the humate material treatments appeared to have healthier turf when compared to both the organic matter and control treatments in Study I.

3) MED results suggested no differences in sampling size and soil sample amount found in LDS in Study II.

4) Results of the 2001 season of Study II confirmed the results observed in 2000 that Naiad wetting agent had no significant effect on soil water-repellency, while Primer wetting agent significantly lowered soil hydrophobicity on LDS caused by hydrophobic soil.

5) No phytotoxicity occurred with recommended application rates of either product used in Study II.

6) Primer wetting agent had no significant effect on moisture retention in both the hydrophobic and non-hydrophobic soils in the presence of differing amounts of Michigan peat moss in Study III.

7) Significant differences were observed between organic matter content. The treatments containing 20% organic matter by weight held significantly more moisture when compared to the other treatments in Study III.

8) As organic matter content increased, the amount of water retained increased accordingly.

9) The trend of increasing water retention with increasing organic matter content was consistent in both hydrophobic and hydrophilic putting green mixes in Study III.

10) Wetting agents do not aid the soil in holding excessive water on putting greens constructed with Michigan peat moss used as organic matter material, as demonstrated in Study III.

Future research in the area of LDS should continue to concentrate on water-repellent soil development and the nature of that condition(s) which facilitate its development. Continued evaluation of the construction mixes in Study I may yield answers to the facilitation of hydrophobic soil. Furthermore, carefully monitored field studies could potentially reveal the developmental stages of LDS due to water-repellent soils as they actually occur. Laboratory studies using different types of organic matter could show a relationship between water retention in hydrophobic soils, in the presence of a wetting agent. However, organic matter does not appear to affect wetting agent performance in hydrophobic or hydrophilic soils. Since the organic matter did not simulate the thatch/mat environment, no conclusions can be drawn in relation to its effect on wetting agent performance.

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**Table of Contents – Study I**

**Fig. 1.1 Excised bentgrass roots**

**Fig. 1.2 Organic matter (Michigan Peat Moss)**

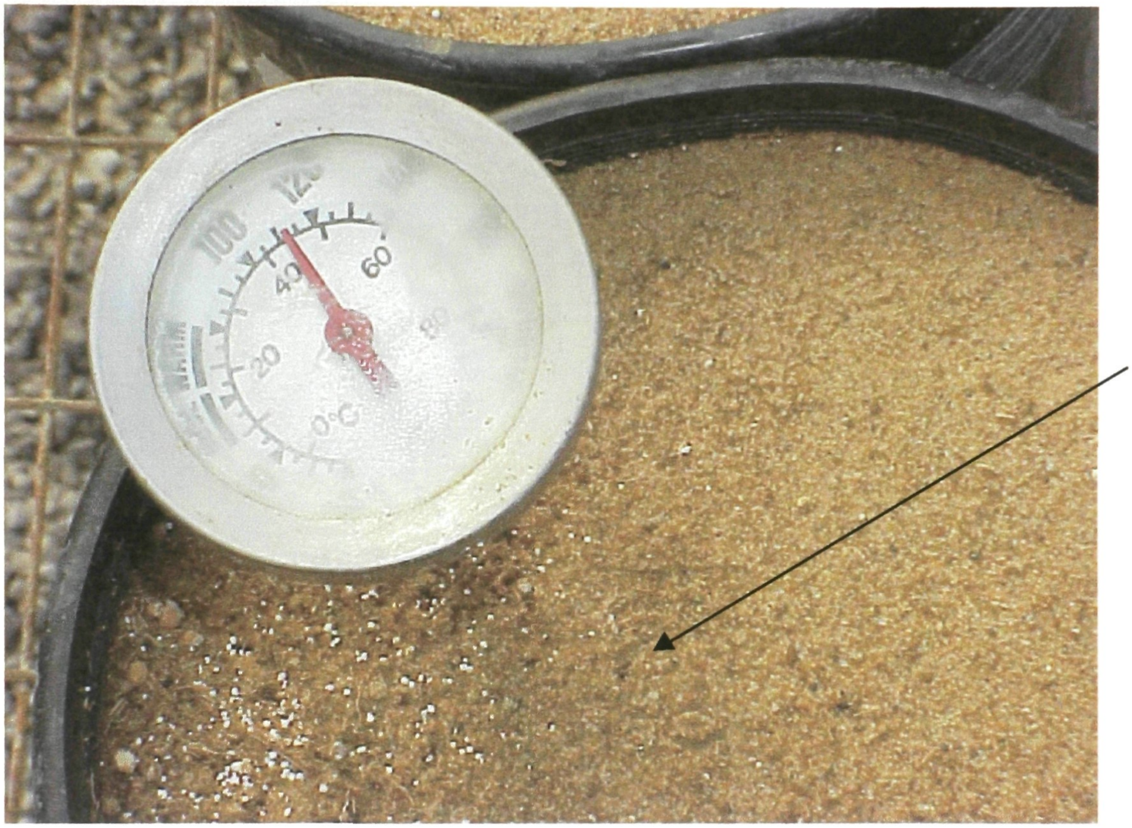



**Fig. 1.3 Humate material**

**Fig. 1.4 Bentgrass sodded on treatment mixes**

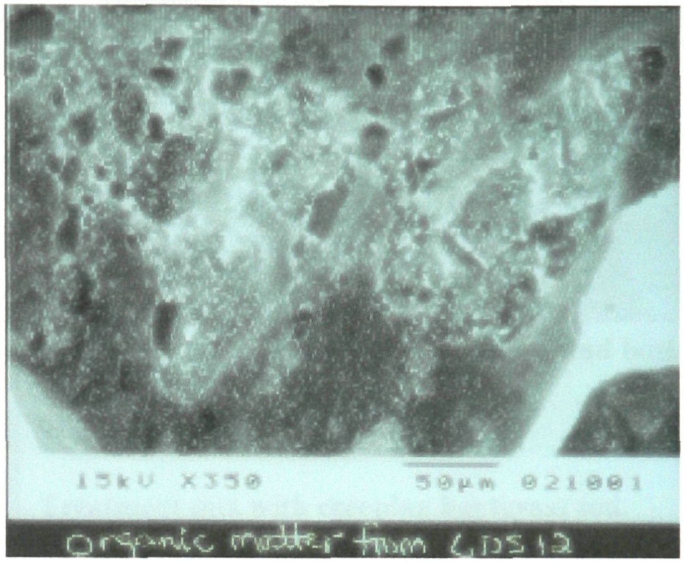
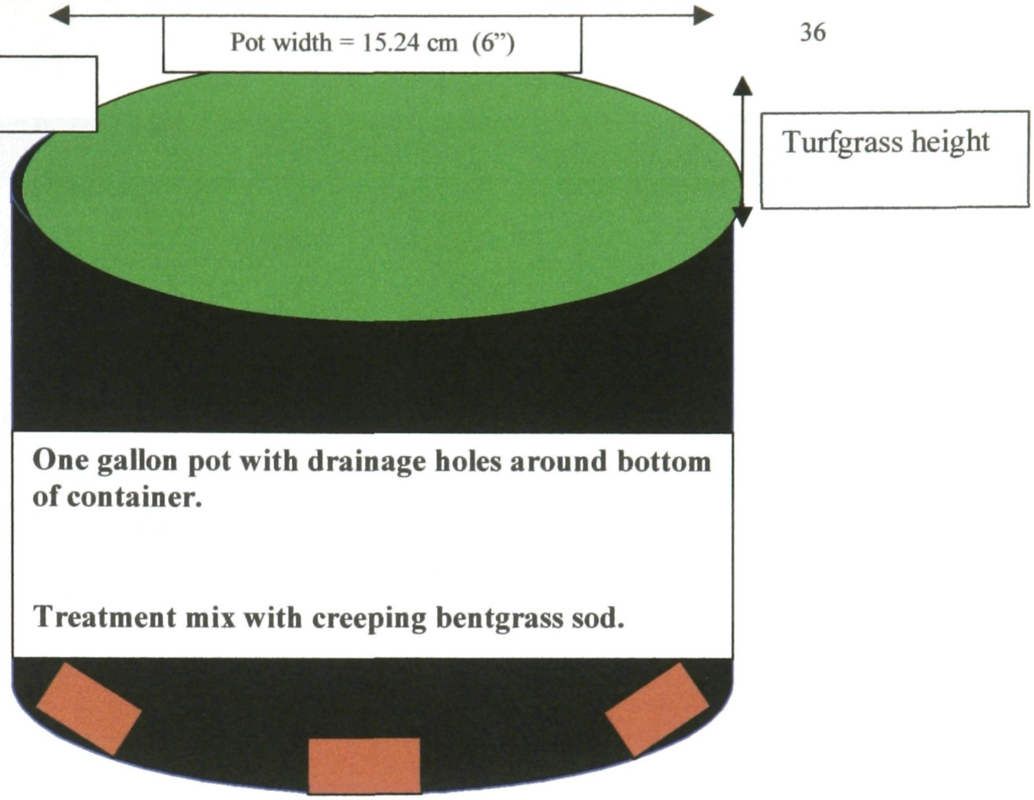



**Fig. 1.5 SEM photograph of organic coating on sand particle**

**Magnified 350 X's (Elmore, 2000)**

Fig. 1.6




Study I Treatment container with and without live, bentgrass sod

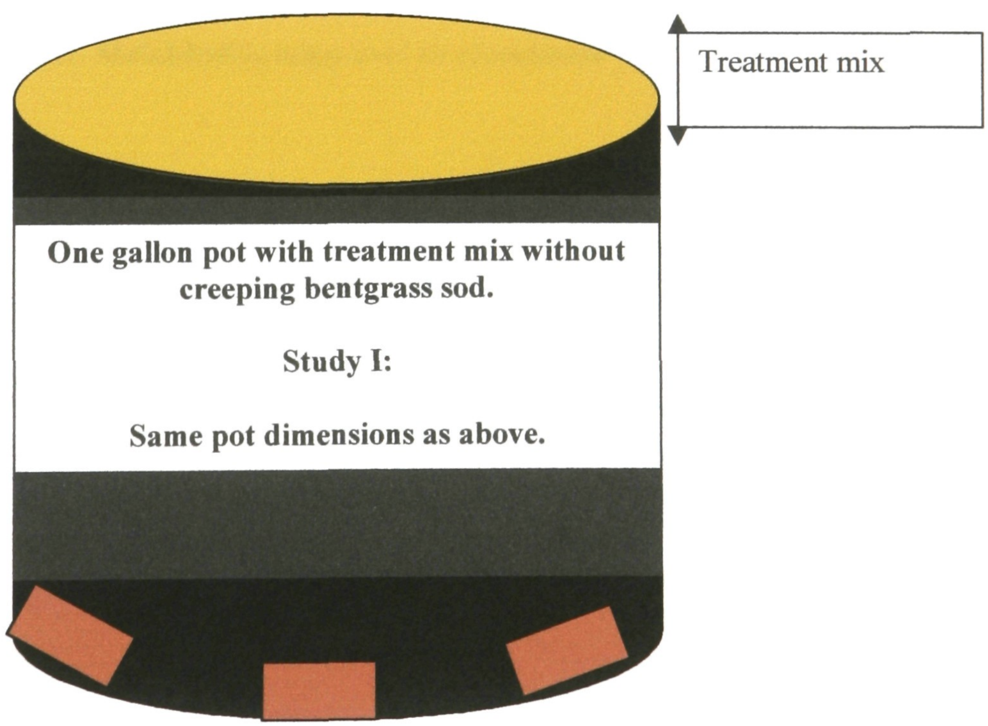


**Fig. 1.7 Metal-halide lamp used in greenhouse**

**Table 1**

**Study I MED results after 13 months of maintenance**

| Treatment | MED result |
| --- | --- |
| Humate material/sand mix | 0.0 |
| Humate material/sand mix with live turf | 0.0 |
| Organic matter/sand mix | 0.0 |
| Organic matter/sand mix with live turf | 0.0 |
| Hydrophilic sand (control) | 0.0 |
| Hydrophilic sand (control) with live turf | 0.0 |
| Excised bentgrass roots – no turf | 0.0 |

*Note: Each of the four replications within each treatment was tested; however, none of them developed the hydrophobic condition within 13 months of maintenance.

**TABLE OF CONTENTS – Study II**

**Fig. 2.8 Experimental green at Western Kentucky University Farm**

**Fig. 2.9 LDS associated with hydrophobic soil on experimental green**

**Fig. 2.10 MED sample cores after sampling with .64 cm diameter probe**


**Fig. 2.11 $CO_2$ sprayer used for wetting agent applications**

**Fig. 2.12 MED soil sample taken with 1.27 cm soil probe to determine hydrophobicity**


**Fig. 2.13 MED soil sample taken with .64 cm soil probe to determine hydrophobicity**

**Fig. 2.14 Application of wetting agent with $CO^2$ sprayer**

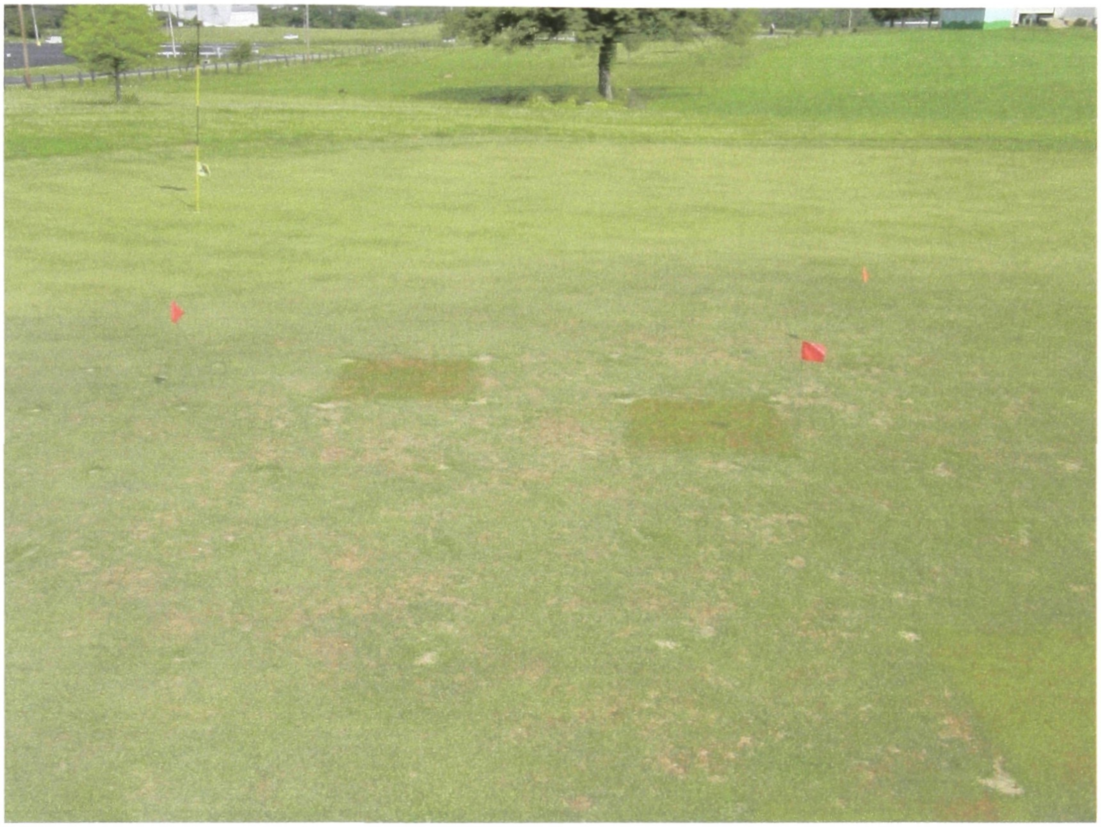
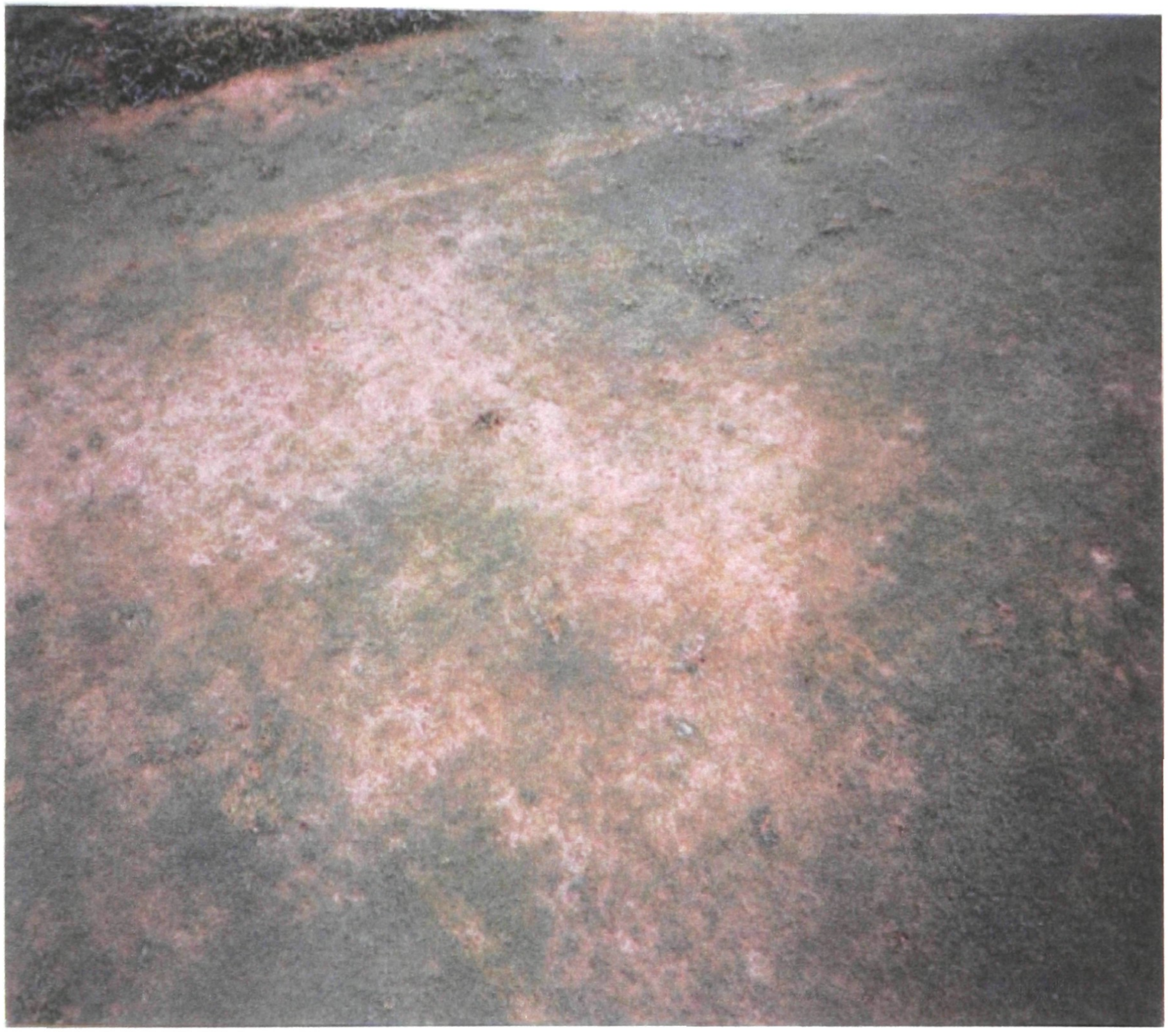


Fig. 2.15 Study II Plots following wetting agent application

**Study II**

**Fig. 2.16 LDS on experimental green**



**Study II**

**Fig. 2.17 Turfgrass damage occurring on experimental green as a result of hydrophobic soil**

**Study I and II**

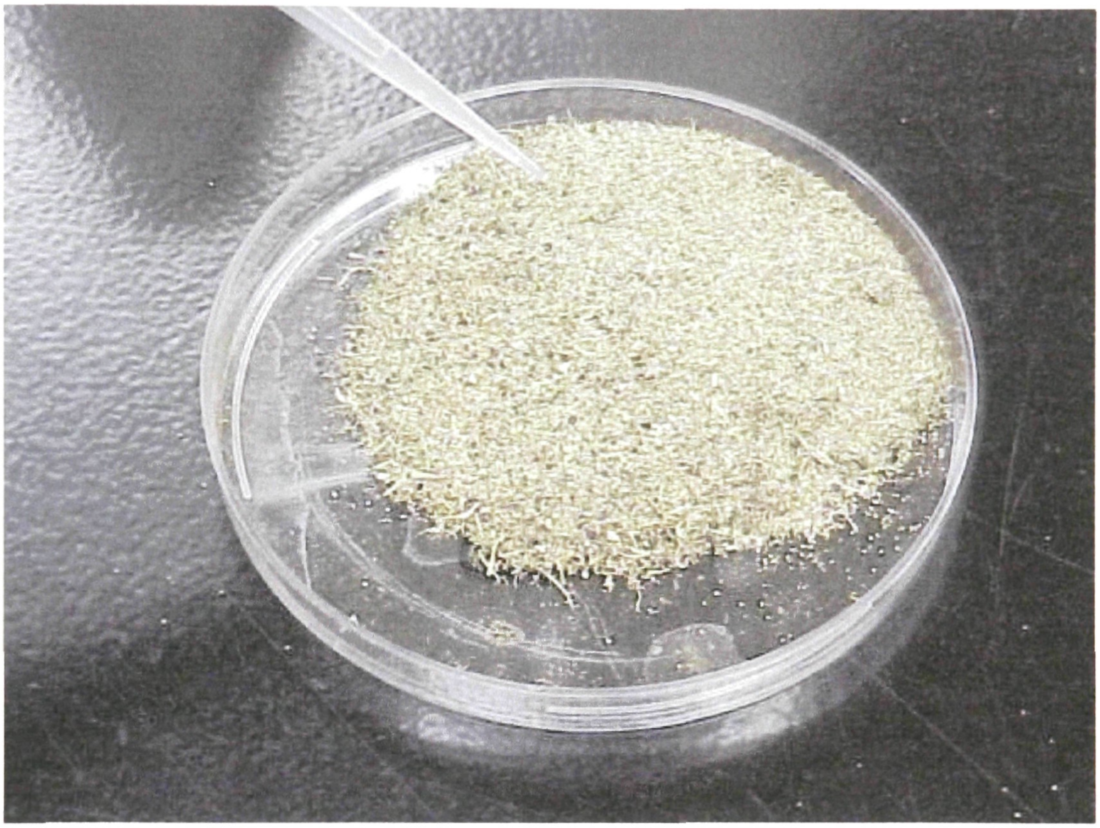


**Fig. 2.18 MED testing using 40 $\mu$l pipette**

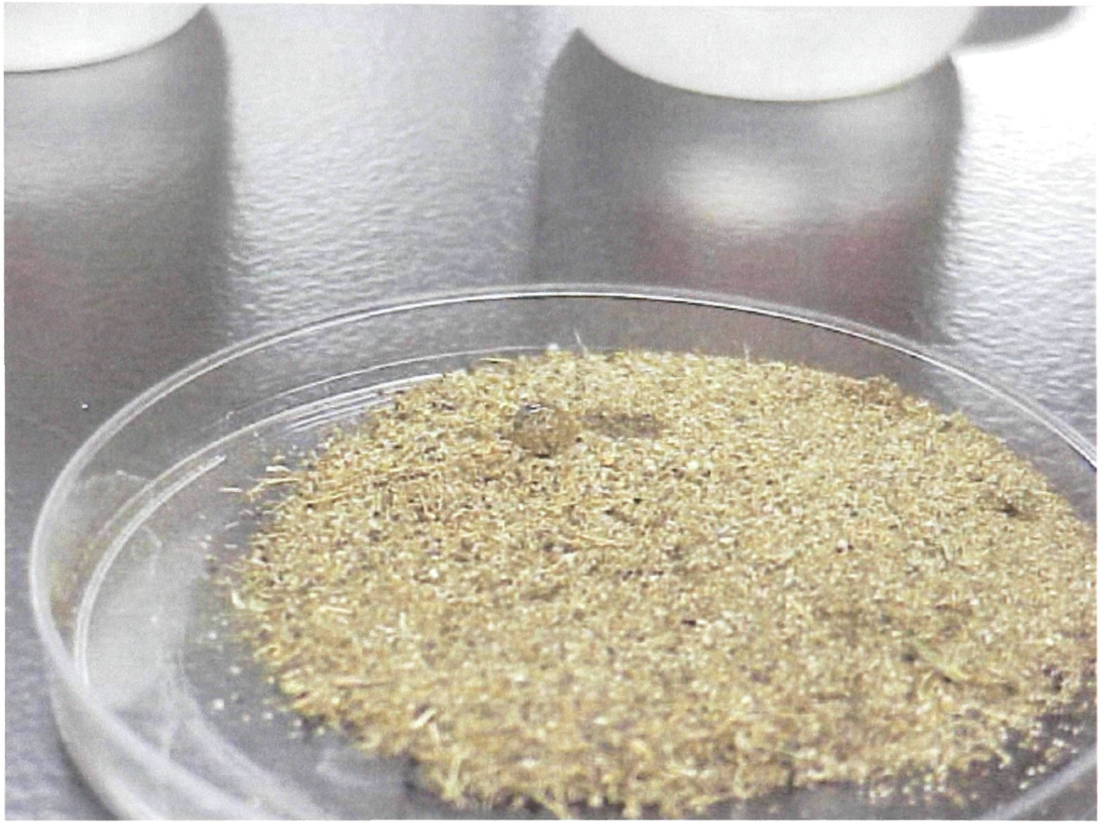


**Fig. 2.19 Hydrophobic soil with bead of water from MED testing**

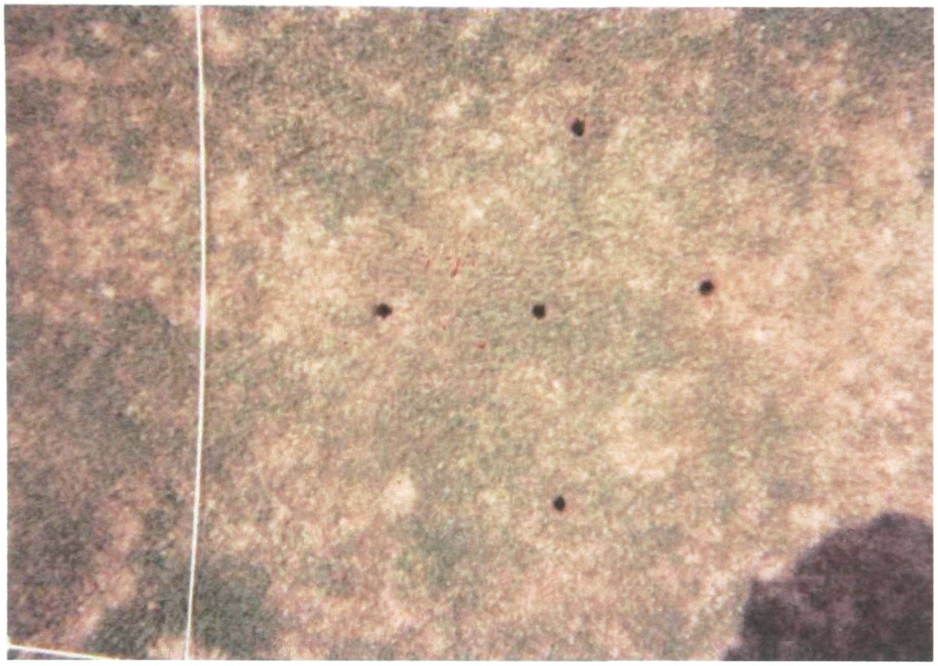
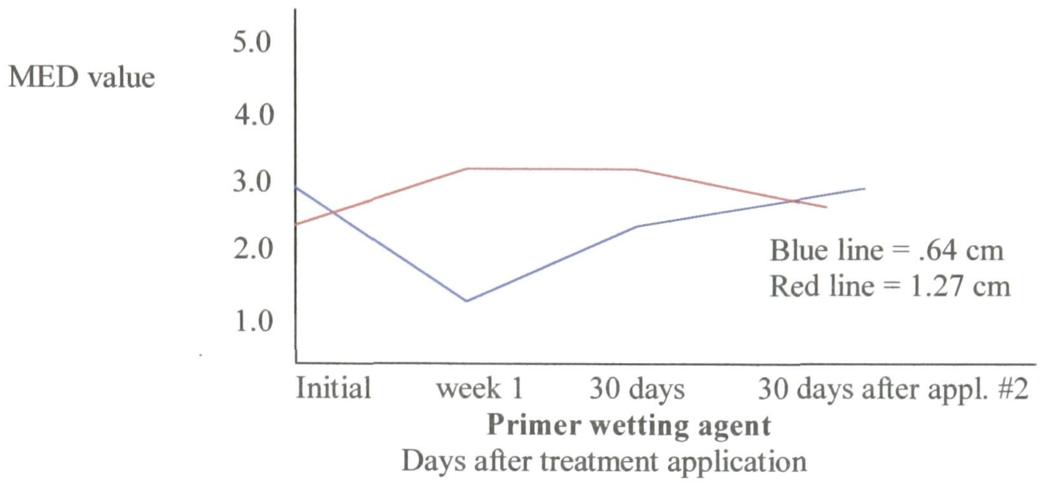


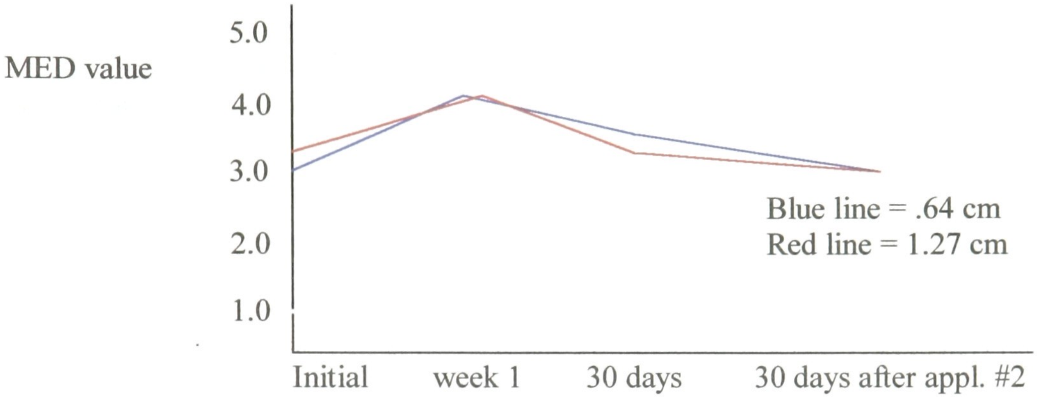
**Fig. 2.20 Desiccation on Naiad wetting agent plots**

**Fig. 2.21 Dollar spot infestation on experimental plots**

**Study II Treatment Means –** Two soil probe sampling sizes .64 and 1.27 cm

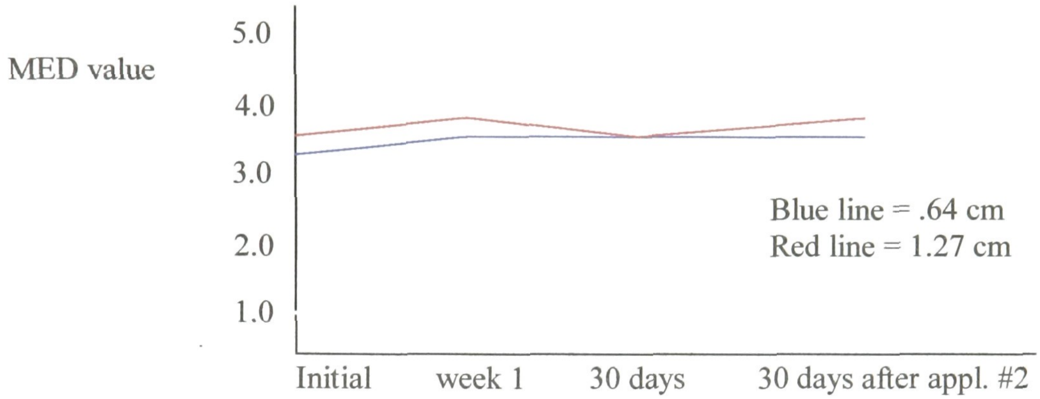


**Study II –** Two soil probe sampling sizes .64 and 1.27 cm



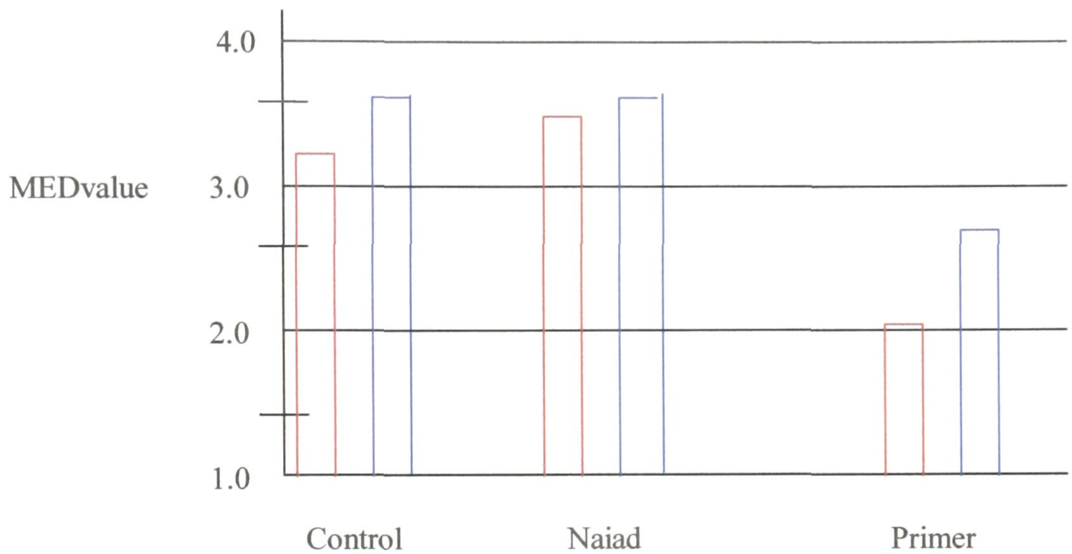

**Naiad wetting agent**
Days after treatment application

**Study II -** Two soil probe sampling sizes .64 and 1.27 cm




**Control**
Days after initial treatment with wetting agents

**Study II** – Comparison of soil probe sizes with two wetting agents

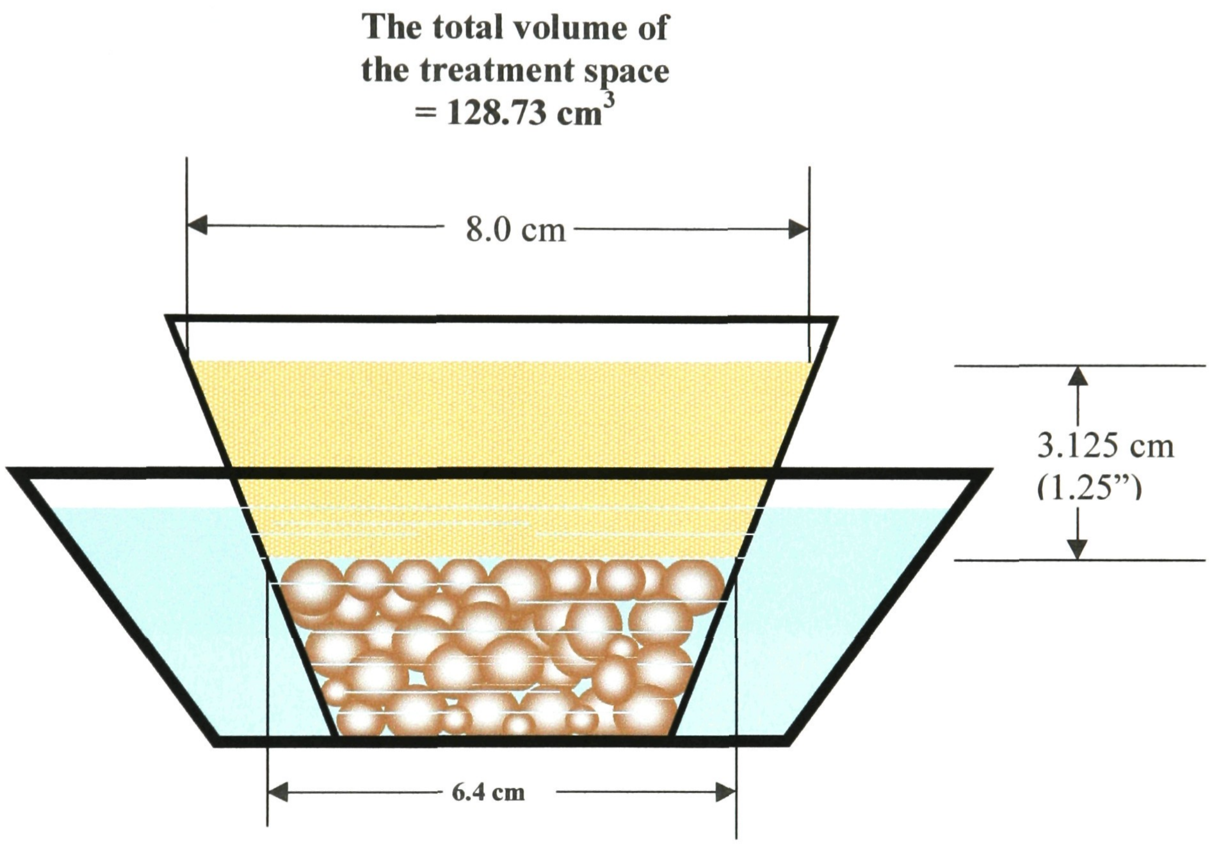



Red line indicates .64 cm sample MED reading

Blue line indicated 1.27 cm sample MED reading

*No significant differences were detected at the ∝ 0.05 level of significance.

**Fig. 3.22 Diagram of treatment cup and measurements**




A diagram for water absorption for all the treatments
**In STUDY III**
(Between the sand and the gravel,
there are two layers of cheese cloth.)

**Fig. 3.23 Mixing and pouring of individual treatment mixes into cups**

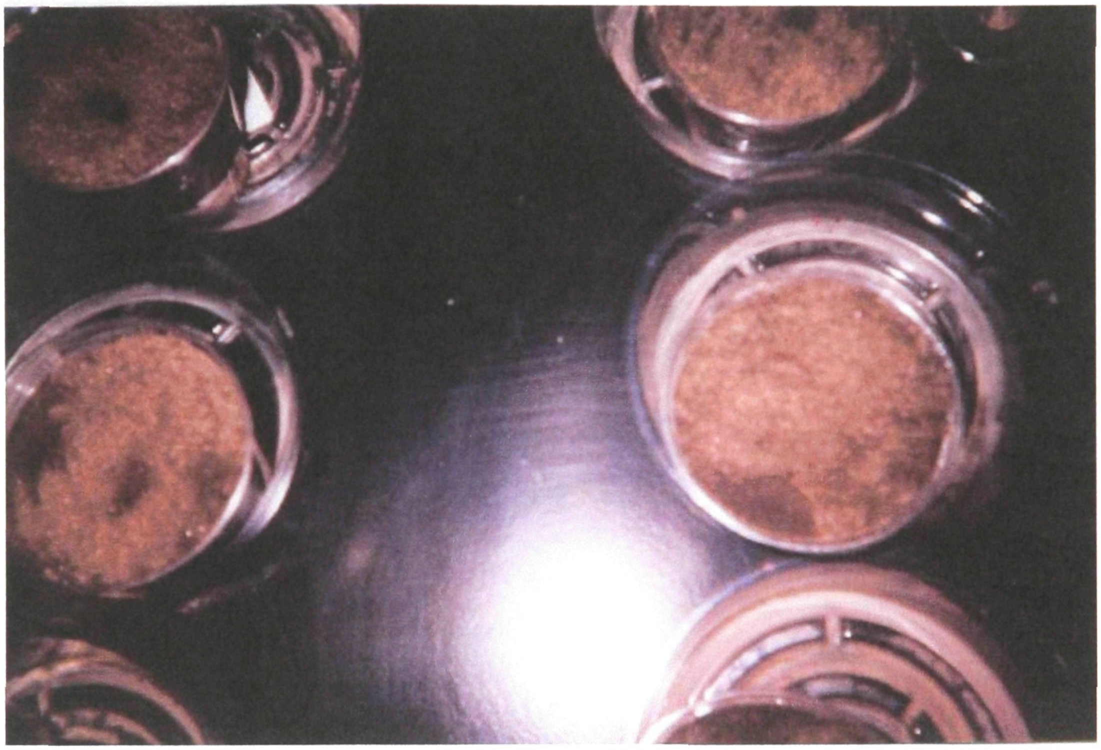


**Fig. 3.24 Hydrophobic soil as seen in control replication during wetting phase**

**Fig. 3.25 Hydrophobic soil containing 20% organic matter by weight in treatment replication prior to wetting phase**

**Fig. 3.26 Hydrophilic sand as seen in control replication during wetting phase**

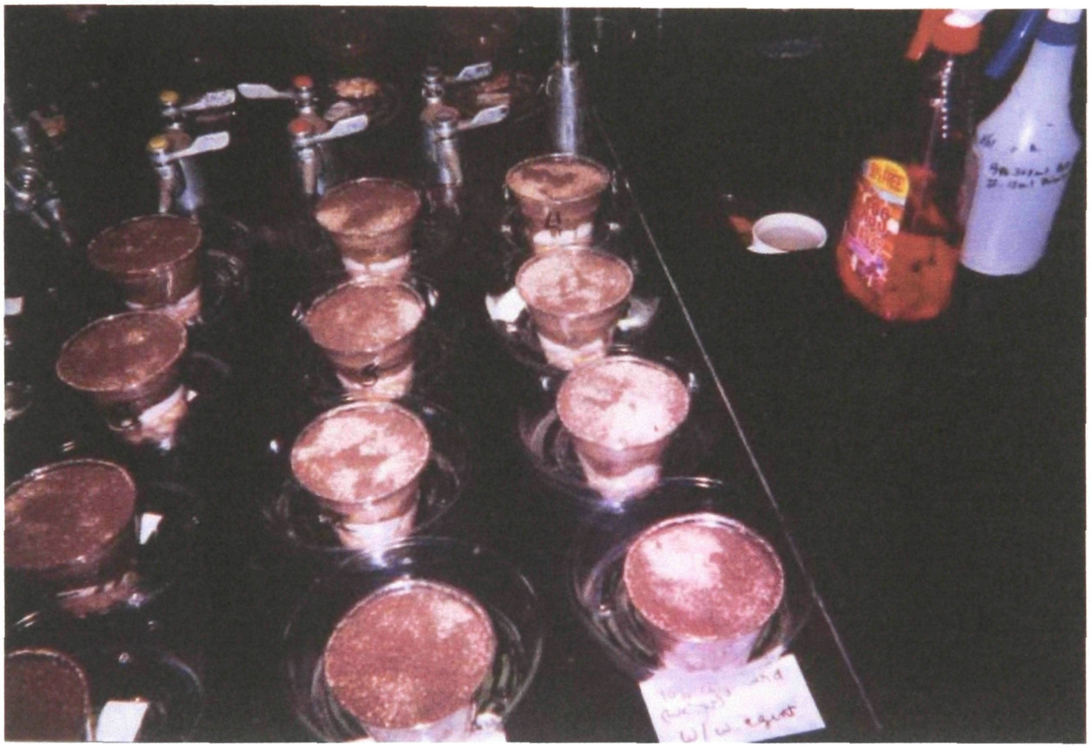


**Fig. 3.27 Hydrophilic sand containing 20% organic matter by weight in treatment replication prior to wetting phase**

**Fig. 3.28 Scale used for weighing each treatment replication daily to compare percent moisture retention**

**Study III**

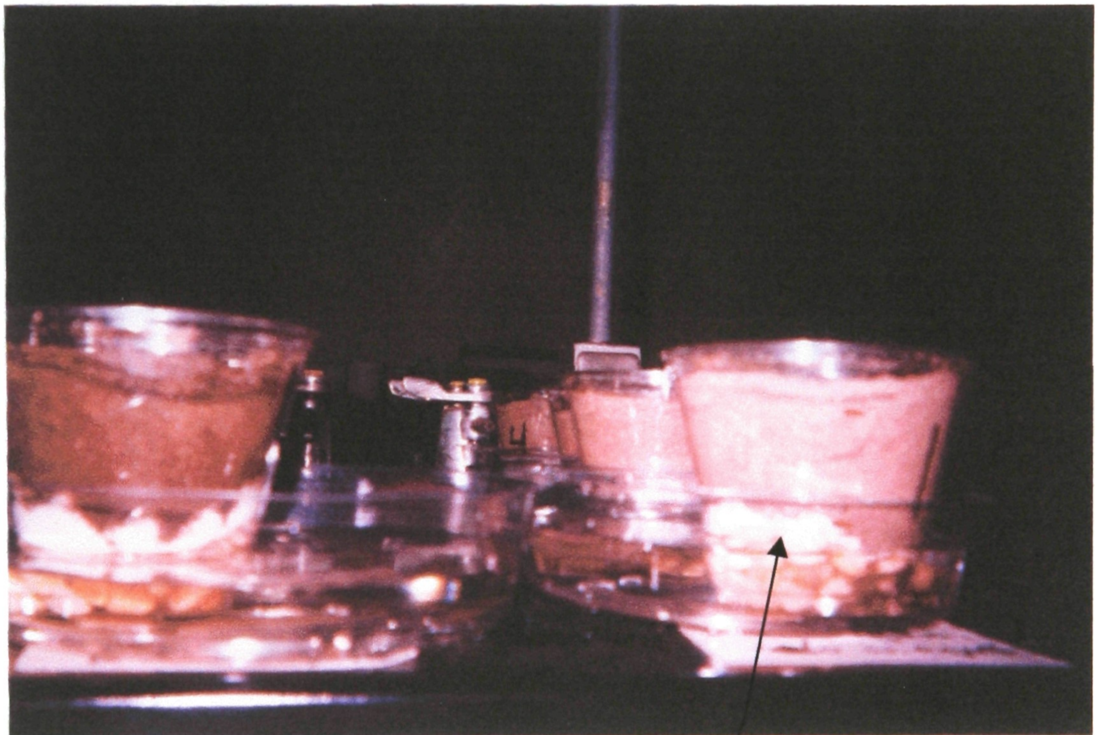



**Fig. 3.29 Sub-irrigation taking place in treatment cups during wetting phase**

**pattern**

**Fig. 3.30 Fingered-flow pattern in hydrophobic soil as described by Jamison, 1949.**

**Fig. 3.31 Application of Primer wetting agent to treatment replications using spray bottle**

**Table 3.1 – Ethanol/water solution calculations for MED testing**

| MED | Ethanol (ml) | distilled water (ml) | |
|---|---|---|---|
| 0.0 | 0.0 | 100.0 | hydrophilic |
| 0.4 | 2.34 | 97.66 | |
| 0.8 | 4.66 | 95.34 | |
| 1.2 | 7.0 | 93.0 | |
| 1.6 | 9.32 | 90.68 | |
| 2.0 | 11.66 | 88.34 | |
| 2.4 | 14.0 | 86.0 | |
| 2.8 | 16.32 | 83.68 | |
| 3.2 | 18.66 | 81.34 | |
| 3.6 | 21.0 | 79.0 | |
| 4.0 | 23.34 | 76.66 | severely hydrophobic |

**Fig. 3.32– Overview of treatments prior to wetting phase**

**Fig. 3.33 Hydrophobic treatments containing organic matter after one week of dry-down phase**

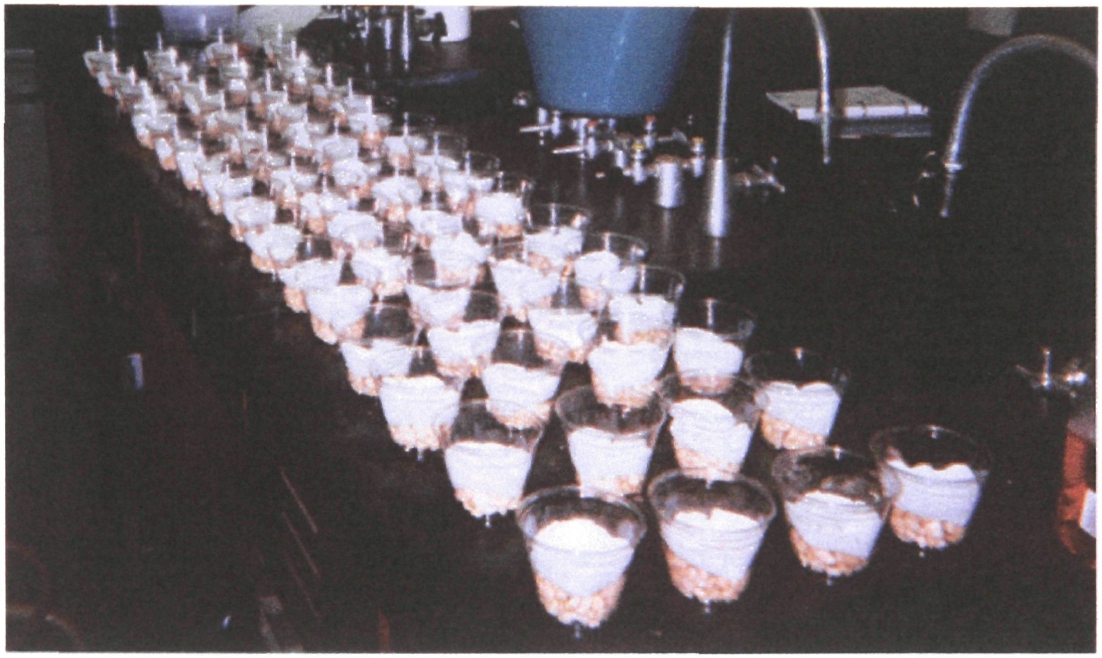
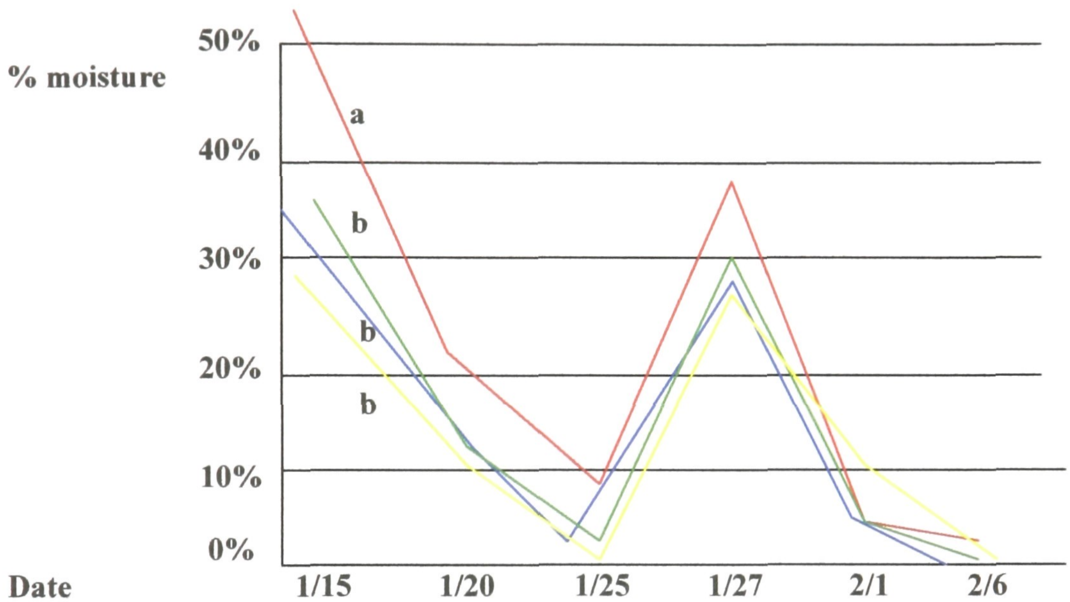


**Fig. 3.34 Treatment cup preparation (based on Figure 16)**

**Fig. 3.35 Treatment cup prior to wetting; demonstrating profile**

**Fig. 3.36 Hydrophobic soil and organic matter prior to combination**

**Study III** – Water retention changes of hydrophobic soil mixes with Primer wetting agent




**20% organic matter (weight) - red line**

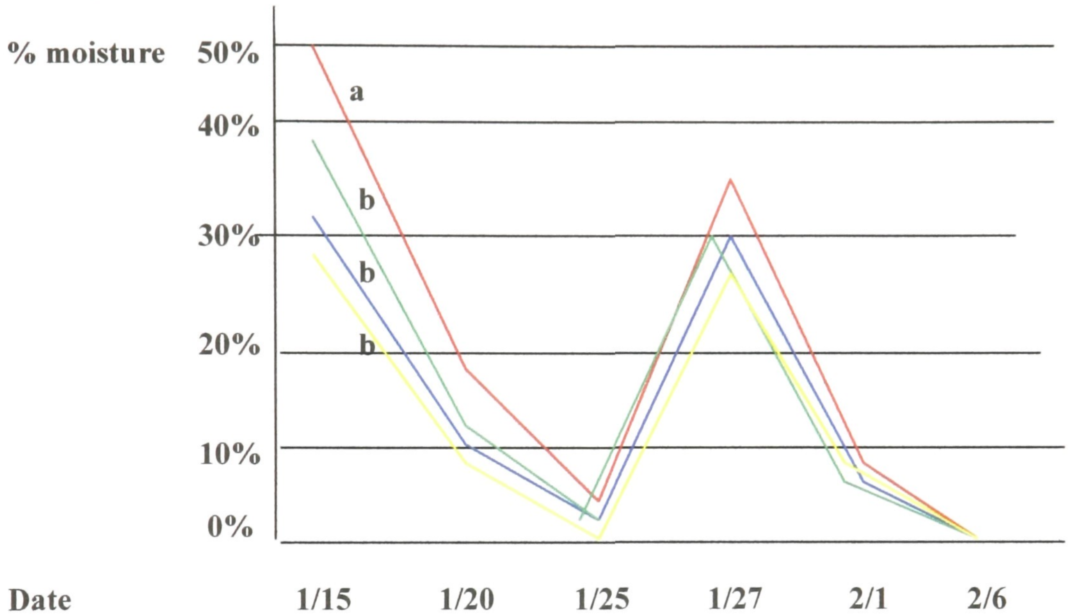
**20% organic matter (volume) – blue line**

**10% organic matter (weight) – green line**

**Hydrophobic soil without added organic matter – yellow line**

***Differences were those occurring at the $\alpha = 0.05$ level of significance. Those differences are represented by a, b, and c.**

**Study III** - Water retention changes of hydrophobic soil mixes without Primer wetting agent




**20% organic matter (weight) - red line**

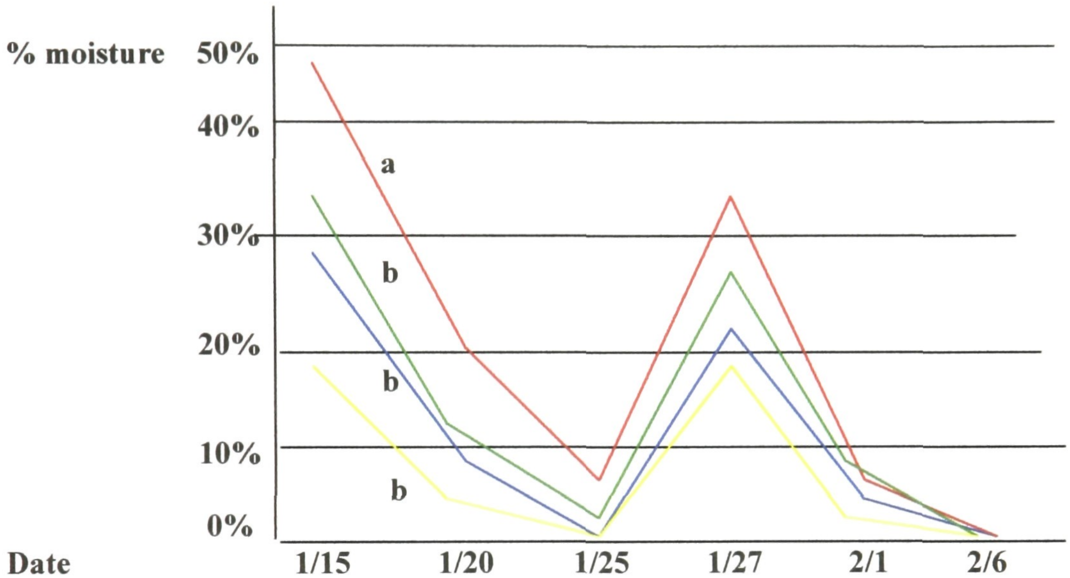
**20% organic matter (volume) – blue line**

**10% organic matter (weight) – green line**

**Hydrophobic soil without added organic matter – yellow line**

***Differences were those occurring at the $\alpha = 0.05$ level of significance. Those differences are represented by a, b, and c.**

**Study III** - Water retention changes of hydrophilic soil mixes without Primer wetting agent




**20% organic matter (weight) - red line**

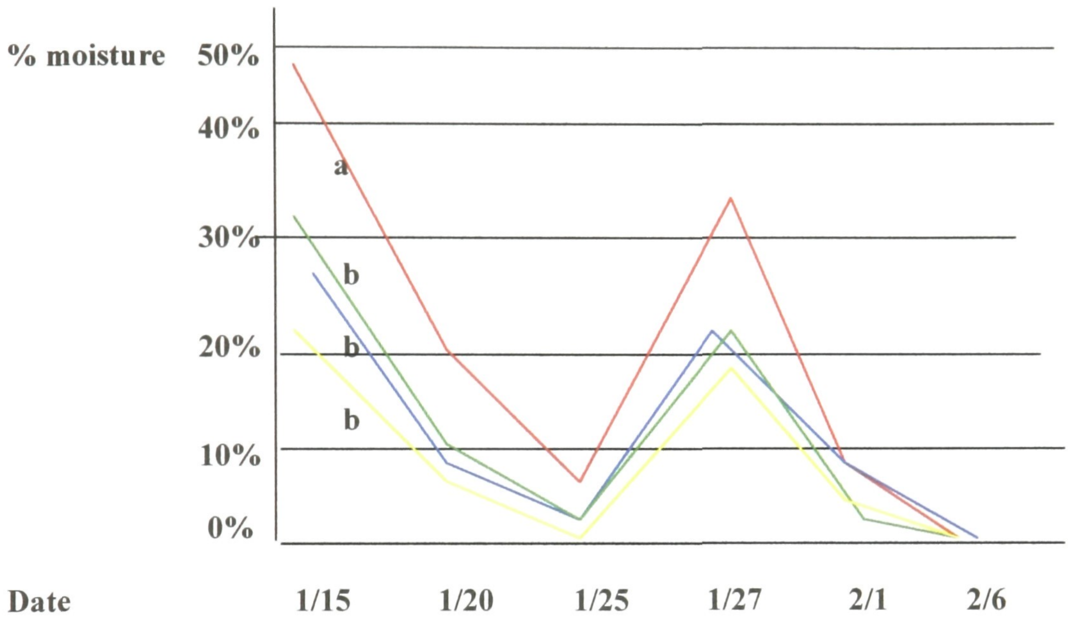
**20% organic matter (volume) – blue line**

**10% organic matter (weight) – green line**

**Hydrophilic soil without added organic matter – yellow line**

***Differences were those occurring at the $\alpha = 0.05$ level of significance. Those differences are represented by a, b, and c.**

**Study III** - Water retention changes of hydrophilic soil mixes without Primer without agent




**20% organic matter (weight) - red line**

**20% organic matter (volume) – blue line**

**10% organic matter (weight) – green line**

**Hydrophilic soil without added organic matter – yellow line**

***Differences were those occurring at the $\alpha = 0.05$ level of significance. Those differences are represented by a, b, and c.**

# Appendices

# Table of Contents

**Study II. – ANOVA**

```
The SAS System       15:18 Wednesday, July 25, 2001   1

                                    The ANOVA Procedure

                                  Class Level Information

                        Class         Levels    Values

                        trt                6    wc2 wc4 wn2 wn4 wp2
wp4

                        size               6    1.3 3.4 3.5 3.7 3.8
4


                                  Number of observations    6
                                        The SAS System       15:18
Wednesday, July 25, 2001   2

                                    The ANOVA Procedure

Dependent Variable: size

                                                  Sum of
      Source                      DF            Squares     Mean Square
F Value    Pr > F

      Model                        5         4.94833333      0.98966667
.          .

      Error                        0         0.00000000       .

      Corrected Total              5         4.94833333


                       R-Square     Coeff Var      Root MSE      size
Mean

                       1.000000             .             .
3.283333


      Source                      DF           Anova SS     Mean Square
F Value    Pr > F

      trt                          5         4.94833333      0.98966667
.          .
                                        The SAS System       15:18
Wednesday, July 25, 2001   3

                                    The ANOVA Procedure

                        Level of           -------------size--------
----
```

```
                         trt           N            Mean            Std
Dev

                         wc2           1       3.70000000
.
                         wc4           1       3.50000000
.
                         wn2           1       4.00000000
.
                         wn4           1       3.80000000
.
                         wp2           1       3.40000000
.
                         wp4           1       1.30000000
.
                                             The SAS System       15:18
Wednesday, July 25, 2001   4

                                          The ANOVA Procedure

                                        Class Level Information

                         Class             Levels    Values

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ip4

                         size                   6    1.3 2.9 3 3.2 3.5
3.8


                                      Number of observations    6
                                             The SAS System       15:18
Wednesday, July 25, 2001   5

                                          The ANOVA Procedure

Dependent Variable: size

                                                     Sum of
      Source                          DF          Squares     Mean Square
F Value    Pr > F

      Model                            5       3.81500000      0.76300000
.       .

      Error                            0       0.00000000        .

      Corrected Total                  5       3.81500000


                        R-Square     Coeff Var      Root MSE      size
Mean

                        1.000000          .              .
2.950000
```

```
     Source                        DF         Anova SS     Mean Square
F Value    Pr > F

     trt                            5      3.81500000      0.76300000
.        .
                                              The SAS System       15:18
Wednesday, July 25, 2001   6

                                           The ANOVA Procedure

                        Level of          -------------size--------
----
                        trt            N             Mean            Std
Dev

                        ic2            1       3.50000000
.
                        ic4            1       3.20000000
.
                        in2            1       3.80000000
.
                        in4            1       2.90000000
.
                        ip2            1       1.30000000
.
                        ip4            1       3.00000000
.
                                              The SAS System       15:18
Wednesday, July 25, 2001   7

                                           The ANOVA Procedure

                                         Class Level Information

                        Class          Levels    Values

                        trt                 6    wc2 wc4 wn2 wn4 wp2
wp4

                        size                6    1.3 3.4 3.5 3.7 3.8
4


                                   Number of observations    6
                                              The SAS System       15:18
Wednesday, July 25, 2001   8

                                           The ANOVA Procedure

Dependent Variable: size

                                                      Sum of
     Source                        DF              Squares     Mean Square
F Value    Pr > F
```

```
     Model                          5      4.94833333      0.98966667
.       .

     Error                          0      0.00000000        .

     Corrected Total                5      4.94833333


                         R-Square     Coeff Var      Root MSE      size
Mean

                         1.000000            .               .
3.283333


     Source                        DF         Anova SS     Mean Square
F Value    Pr > F

     trt                            5      4.94833333      0.98966667
.       .
                                              The SAS System       15:18
Wednesday, July 25, 2001   9

                                           The ANOVA Procedure

                         Level of          -------------size--------
----
                         trt            N             Mean             Std
Dev

                         wc2            1       3.70000000
.
                         wc4            1       3.50000000
.
                         wn2            1       4.00000000
.
                         wn4            1       3.80000000
.
                         wp2            1       3.40000000
.
                         wp4            1       1.30000000
.
                                              The SAS System       15:18
Wednesday, July 25, 2001  10

                                           The ANOVA Procedure

                                         Class Level Information

                      Class          Levels    Values

                      trt                 6    3dc2 3dc4 3dn2 3dn4
3dp2 3dp4

                      size                4    2.4 2.5 3.1 3.3
```

Number of observations 6

The SAS System 15:18

Wednesday, July 25, 2001 11

The ANOVA Procedure

Dependent Variable: size

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 0.79500000 | 0.15900000 | . | . |
| Error | 0 | 0.00000000 | . | | |
| Corrected Total | 5 | 0.79500000 | | | |

| R-Square | Coeff Var | Root MSE | size Mean |
|---|---|---|---|
| 1.000000 | . | . | 2.950000 |

| Source | DF | Anova SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| trt | 5 | 0.79500000 | 0.15900000 | . | . |

The SAS System 15:18

Wednesday, July 25, 2001 12

The ANOVA Procedure

| Level of trt | N | -------------size------------ Mean | Std Dev |
|---|---|---|---|
| 3dc2 | 1 | 3.30000000 | . |
| 3dc4 | 1 | 3.10000000 | . |
| 3dn2 | 1 | 3.30000000 | . |
| 3dn4 | 1 | 3.10000000 | . |
| 3dp2 | 1 | 2.40000000 | . |
| 3dp4 | 1 | 2.50000000 | . |

The SAS System 15:18

Wednesday, July 25, 2001 13

```
                                   The ANOVA Procedure

                                Class Level Information

                 Class          Levels    Values

                 trt                 6    3ddc2 3ddc4 3ddn2 3ddn4
3ddp2 3ddp4

                 size                4    2.8 3.1 3.4 3.5


                               Number of observations    6
                                   The SAS System       15:18
Wednesday, July 25, 2001  14

                                   The ANOVA Procedure

Dependent Variable: size

                                            Sum of
      Source                      DF       Squares     Mean Square
F Value    Pr > F

      Model                        5    0.54833333      0.10966667
.        .

      Error                        0    0.00000000          .

      Corrected Total              5    0.54833333


                    R-Square     Coeff Var      Root MSE      size
Mean

                    1.000000             .             .
3.183333


      Source                      DF       Anova SS     Mean Square
F Value    Pr > F

      trt                          5    0.54833333      0.10966667
.        .
                                   The SAS System       15:18
Wednesday, July 25, 2001  15

                                   The ANOVA Procedure

                    Level of           -------------size--------
----
                    trt           N              Mean            Std
Dev

                    3ddc2         1        3.50000000
.
```

| | | |
|---|---|---|
| 3ddc4 | 1 | 3.40000000 |
| 3ddn2 | 1 | 3.50000000 |
| 3ddn4 | 1 | 3.10000000 |
| 3ddp2 | 1 | 2.80000000 |
| 3ddp4 | 1 | 2.80000000 |

## Study III - Anova

```
data Study III day1;
input  trt $ wlost;
cards;

hvwo 1.87
hvwo 1.20
hvwo 1.56
hvwo 0.55

hvw 0.64
hvw 2.46
hvw 1.25
hvw 1.17

hw 2.62
hw 3.30
hw 3.46
hw 3.72

hwo 2.28
hwo 1.45
hwo 2.53
hwo 2.95

horw 2.28
horw 1.45
horw 2.53
horw 2.95

horwo 0.97
horwo 1.47
horwo 2.22
horwo 1.54

how 1.63
how 2.09
how 1.58
how 1.09

howo 1.51
howo 2.29
howo 1.86
howo 1.32

sw 0.00
sw 0.00
sw 0.75
sw 1.05

swo 0.00
swo 0.05
swo 0.00
swo 0.00
```

```
sorw 2.57
sorw 0.32
sorw 0.97
sorw 0.00

sorwo 1.40
sorwo 0.81
sorwo 1.84
sorwo 1.38

svow 3.74
svow 3.55
svow 1.66
svow 1.42

svowo 1.33
svowo 2.34
svowo 2.66
svowo 2.91

sow 0.90
sow 0.00
sow 0.00
sow 2.47

sowo 1.95
sowo 1.17
sowo 4.17
sowo 1.42

run;

data study III day2;
input  trt $ wlost;
cards;

hvwo 10.75
hvwo 7.60
hvwo 9.78
hvwo 7.75

hvw 5.66
hvw 5.36
hvw 4.28
hvw 5.99

hw 18.55
hw 11.22
hw 11.34
hw 11.57

hwo 11.97
hwo 10.82
hwo 13.69
hwo 13.81

horw 5.68
```

horw 7.31
horw 2.30
horw 2.04

horwo 2.86
horwo 2.49
horwo 3.50
horwo 4.75

how 4.20
how 4.18
how 2.74
how 6.73

howo 4.72
howo 4.68
howo 6.15
howo 4.77

sw 21.96
sw 21.97
sw 13.78
sw 20.24

swo 17.42
swo 16.57
swo 19.82
swo 20.89

sorw 11.67
sorw 9.08
sorw 8.81
sorw 11.41

sorwo 15.33
sorwo 15.14
sorwo 12.51
sorwo 12.51

svow 13.64
svow 12.70
svow 13.16
svow 8.70

svowo 15.30
svowo 13.15
svowo 13.87
svowo 14.09

sow 8.58
sow 6.47
sow 5.59
sow 7.04

sowo 11.97
sowo 10.59
sowo 10.42

```
sowo 9.22

run;

data study III day3;
input  trt $ wlost'
cards;


hvowo 26.63
hvowo 25.15
hvowo 22.54
hvowo 22.75

hvow 24.68
hvow 21.59
hvow 19.30
hvow 19.68

hw 26.94
hw 18.65
hw 18.71
hw 18.18

hwo 22.79
hwo 19.38
hwo 19.48
hwo 21.18

horw 26.36
horw 22.23
horw 16.89
horw 16.14

horwo 19.90
horwo 18.07
horwo 18.20
horwo 20.16

how 19.98
how 18.91
how 15.82
how 18.33

howo 20.30
howo 18.25
howo 18.90
howo 17.54

sw 28.30
sw 26.41
sw 21.08
sw 25.93

swo 23.11
swo 23.06
swo25.27
```

```
swo24.96

sorw 19.96
sorw 18.35
sorw 19.15
sorw 22.12

sorwo 23.69
sorwo 23.11
sorwo 20.23
sorwo 21.21

sovw 20.71
sovw 19.51
sovw 19.37
sovw 14.95

sovwo 21.77
sovwo 20.98
sovwo 20.13
sovwo 21.57

sow 16.22
sow 13.54
sow 14.64
sow 15.67

sowo 20.57
sowo 19.14
sowo 17.46
sowo 17.39

run;


data study III day4;
input  $ trt wlost;
cards;

hvowo 39.52
hvowo 39.00
hvowo 33.82
hvowo 35.71

hvow 39.16
hvow 35.00
hvow 31.76
hvow 31.81

hw 39.37
hw 31.60
hw 31.19
hw 31.34

hwo 36.77
hwo 19.38
hwo 32.20
```

hwo 34.81

horw 42.07
horw 34.55
horw 28.76
horw 27.96

horwo 33.63
horwo 30.82
horwo 30.50
horwo 33.47

how 33.09
how 31.25
how 26.75
how 28.40

howo 32.99
howo 29.83
howo 29.88
howo 28.69

sw 42.89
sw 40.74
sw 35.17
sw 40.47

swo 37.04
swo 38.24
swo 38.74
swo 38.81

sorw 33.82
sorw 32.93
sorw 34.64
sorw 36.19

sorwo 36.52
sorwo 35.60
sorwo 32.19
sorwo 33.26

sovw 34.78
sovw 34.03
sovw 33.37
sovw 28.06

sovwo 34.18
sovwo 34.83
sovwo 33.27
sovwo 37.00

sow 28.38
sow 24.89
sow 27.55
sow 27.58

```
sowo 32.95
sowo 31.10
sowo 28.48
sowo 28.91

run;


data study III day5;
input  trt $ wlost;
cards;

hvowo 49.82
hvowo 49.83
hvowo 42.88
hvowo 46.16

51.13
45.71
41.56
41.57

hvow 49.22
hvow 41.84
hvow 41.26
hvow 42.13

hw 47.80
hw 43.67
hw 42.26
hw 45.75

hwo 53.93
hwo 44.02
hwo 37.84
hwo 37.14

horw 44.09
horw 40.58
horw 39.95
horw 43.73

horwo 42.66
horwo 40.54
horwo 35.05
horwo 36.25

how 42.61
how 38.47
how 38.91
how 37.38

sw 54.83
sw 52.62
sw 46.67
sw 52.51
```

```
swo 48.43
swo 50.85
swo 49.78
swo 50.07

sorw 44.39
sorw 43.94
sorw 46.23
sorw 46.96

sorwo 46.87
sorwo 45.43
sorwo 41.47
sorwo 42.57

sovw 46.77
sovw 45.52
sovw 44.41
sovw 38.53

sovwo 44.06
sovwo 45.91
sovwo 43.64
sovwo 49.34

sow 37.99
sow 33.90
sow 37.77
sow 36.79

sowo 42.80
sowo 40.60
sowo 37.10
sowo 37.83


run;


data study III day 6;
input trt $ wlost;
cards;

hvowo 60.90
hvowo 61.83
hvowo 52.97
hvowo 57.90

hvow 64.10
hvow 56.68
hvow 52.56
hvow 52.57

hw 59.97
hw 53.02
hw 52.29
hw 54.05
```

hwo 59.86
hwo 55.57
hwo 54.31
hwo 57.73

horw 66.69
horw 54.32
horw 46.64
horw 48.81

horwo 55.13
horwo 51.20
horwo 50.41
horwo 55.03

how 53.61
how 51.42
how 43.99
how 44.75

howo 53.56
howo 47.93
howo 48.18
howo 46.82

sw 68.00
sw 65.75
sw 70.98
sw 65.82

swo 61.01
swo 64.93
swo 62.10
swo 62.80

sorw 56.14
sorw 56.16
sorw 58.89
sorw 59.13

sorwo 58.23
sorwo 56.30
sorwo 51.84
sorwo 52.94

sovw 58.98
sovw 58.32
sovw 56.76
sovw 50.26

sovwo 55.90
sovwo 58.16
sovwo 55.23
sovwo 62.69

sow 48.76

```
sow 43.98
sow 49.06
sow 46.97

sowo 53.75
sowo 51.20
sowo 46.81
sowo 47.69

run;

data study III day7;
input trt $ wlost;
cards;

hvowo 74.66
hvowo 76.94
hvowo 65.66
hvowo 72.92

hvow 76.87
hvow 70.90
hvow 66.29
hvow 66.18

hw 73.56
hw 66.85
hw 65.98
hw 68.39

hwo 74.89
hwo 70.05
hwo 68.05
hwo 72.05

horw 79.12
horw 68.20
horw 59.82
horw 62.21

horwo 70.15
horwo 65.55
horwo 64.42
horwo 70.11

how 67.34
how 65.17
how 56.73
how 55.20

howo 67.05
howo 61.15
howo 60.61
howo 60.00

sw 84.21
sw 82.02
```

```
sw 75.47
sw 82.32

swo 77.95
swo 82.33
swo 77.57
swo 78.58

sorw 70.72
sorw 71.30
sorw 74.36
sorw 73.66

sorwo 72.67
sorwo 70.22
sorwo 65.46
sorwo 66.92

sovw 75.00
sovw 75.03
sovw 73.70
sovw 65.41

sovwo 69.48
sovwo 73.45
sovwo 70.70
sovwo 79.62

sow 62.69
sow 57.82
sow 64.16
sow 60.49

sowo 67.83
sowo 65.01
sowo 60.18
sowo 61.47

run;


data study III day8;
input trt $ wlost;
cards;

hvowo 80.67
hvowo 82.46
hvowo 72.56
hvowo 78.78

hvow 81.28
hvow 77.25
hvow 73.28
hvow 72.78

hw 82.09
hw 74.64
```

hw 73.46
hw 75.94

hwo 83.17
hwo 78.52
hwo 75.77
hwo 79.78

horw 83.10
horw 73.97
horw 68.44
horw 70.42

horwo 77.90
horwo 74.50
horwo 73.27
horwo 79.05

how 73.90
how 72.83
how 64.71
how 59.80

howo 74.07
howo 69.02
howo 68.36
howo 67.53

sw 94.08
sw 92.14
sw 84.32
sw 91.10

swo 87.04
swo 91.31
swo 87.46
swo 88.88

sorw 78.31
sorw 78.04
sorw 80.05
sorw 78.63

sorwo 80.10
sorwo 77.40
sorwo 73.79
sorwo 75.45

sovw 83.84
sovw 84.49
sovw 81.73
sovw 72.32

sovwo 76.25
sovwo 80.12
sovwo 77.37
sovwo 88.53

```
sow 70.96
sow 65.37
sow 69.97
sow 69.09

sowo 75.18
sowo 73.15
sowo 67.42
sowo 69.30

run;


data study III day9;
input $ trt wlost;
cards;

hvowo 86.18
hvowo 86.83
hvowo 80.80
hvowo 83.59

hvow 85.58
hvow 82.53
hvow 79.55
hvow 79.91

hw 88.17
hw 84.34
hw 83.58
hw 85.19

hwo 89.19
hwo 88.05
hwo 84.94
hwo 88.20

horw 87.14
horw 79.32
horw 77.24
horw 78.40

horwo 83.40
horwo 82.50
horwo 81.48
horwo 86.04

how 79.63
how 80.04
how 74.30
how 64.88

howo 79.98
howo 77.43
howo 76.08
howo 75.92
```

```
sw 99.23
sw 98.49
sw 95.84
sw 97.41

swo 95.59
swo 97.31
swo 95.61
swo 96.21

sorw 83.89
sorw 83.25
sorw 84.81
sorw 83.07

sorwo 85.57
sorwo 83.09
sorwo 81.50
sorwo 82.31

sovw 93.99
sovw 92.22
sovw 89.67
sovw 78.18

sovwo 81.64
sovwo 84.67
sovwo 82.71
sovwo 95.19

sow 78.58
sow 73.53
sow 75.33
sow 76.94

sowo 80.76
sowo 79.92
sowo 75.87
sowo 77.85

run;

data study III day10;
input trt $ wlost;
cards;

hvowo 89.53
hvowo 90.22
hvowo 85.42
hvowo 87.31

hvow 88.31
hvow 83.07
hvow 84.76
hvow 84.46
```

hw 91.87
hw 89.43
hw 89.14
hw 90.19

hwo 93.62
hwo 92.42
hwo 89.93
hwo 92.46

horw 90.39
horw 83.35
horw 82.06
horw 83.54

horwo 87.86
horwo 86.90
horwo 86.81
horwo 91.28

how 83.89
how 84.98
how 80.38
how 68.38

howo 84.10
howo 82.62
howo 81.09
howo 81.45

sw 100.69
sw 100.43
sw 99.86
sw 100.55

swo 85.19
swo 100.09
swo 98.85
swo 99.44

sorw 88.04
sorw 87.12
sorw 88.48
sorw 86.67

sorwo 88.71
sorwo 84.83
sorwo 85.21
sorwo 85.75

sovw 106.19
sovw 137.10
sovw 127.92
sovw 127.00

sovwo 85.15
sovwo 87.86

```
sovwo 86.38
sovwo 99.80

sow 83.53
sow 78.71
sow 79.47
sow 81.43

sowo 84.66
sowo 84.14
sowo 81.35
sowo 82.87

run;

data study III day11;
input trt $ wlost;
cards;

hvowo 92.08
hvowo 92.67
hvowo 88.33
hvowo 90.78

hvow 91.49
hvow 89.83
hvow 87.85
hvow 87.44

hw 94.37
hw 92.43
hw 92.32
hw 93.21

hwo 95.97
hwo 95.14
hwo 92.93
hwo 94.97

horw 92.86
horw 86.29
horw 85.94
horw 87.42

horwo 90.36
horwo 89.59
horwo 89.69
horwo 94.26

how 86.80
how 88.27
how 84.02
how 70.75

howo 86.89
howo 85.79
howo 84.28
```

```
howo 84.87

sw 101.59
sw 101.70
sw 101.53
sw 101.55

swo 101.11
swo 101.56
swo 100.95
swo 101.56

sorw 90.20
sorw 89.48
sorw 90.85
sorw 88.75

sorwo 91.41
sorwo 89.21
sorwo 88.48
sorwo 88.74

sovw 103.58
sovw 100.32
sovw 98.10
sovw 86.15

sovwo 87.58
sovwo 90.13
sovwo 88.87
sovwo 102.63

sow 86.52
sow 81.84
sow 82.36
sow 84.19

sowo 87.23
sowo 86.69
sowo 84.52
sowo 85.99

run;

data study III day12;
input trt $ wlost;
cards;

hvowo 94.35
hvowo 94.92
hvowo 91.18
hvowo 93.35

hvow 93.79
hvow 92.41
hvow 90.81
hvow 90.42
```

```
hw 96.52
hw 95.05
hw 95.09
hw 95.77

hwo 97.95
hwo 97.29
hwo 95.39
hwo 97.21

horw 95.19
horw 89.31
horw 89.02
horw 90.65

horwo 92.81
horwo 92.31
horwo 92.37
horwo 97.15

how 89.70
how 91.68
how 87.63
how 73.27

howo 89.74
howo 89.04
howo 87.55
howo 88.35

sw 100.85
sw 100.90
sw 100.79
sw 100.85

swo 100.70
swo 100.77
swo 100.80
swo 100.87

sorw 92.59
sorw 91.97
sorw 93.31
sorw 90.95

sorwo 93.56
sorwo 91.38
sorwo 90.90
sorwo 91.00

sovw 106.35
sovw 102.91
sovw 100.90
sovw 88.42

sovwo 89.43
```

```
sovwo 91.96
sovwo 90.78
sovwo 104.99

sow 89.58
sow 85.01
sow 85.50
sow 86.98

sowo 89.98
sowo 89.33
sowo 87.75
sowo 89.01

run;

data study III day 13;
input trt $ wlost;
cards;

hvowo 10.52
hvowo 13.76
hvowo 15.71
hvowo 14.53

hvow 14.30
hvow 15.35
hvow 12.76
hvow 15.18

hw 13.88
hw 10.28
hw 10.94
hw 10.26

hwo 7.70
hwo 18.07
hwo 10.87
hwo 13.38

horw 16.42
horw 12.94
horw 11.63
horw 11.18

horwo 14.13
horwo 12.07
horwo 12.78
horwo 12.21

how 12.98
how 11.74
how 11.06
how 10.23

howo 13.35
howo 12.76
```

```
howo 11.97
howo 11.95

sw 12.74
sw 13.35
sw 11.60
sw 12.72

swo 10.56
swo 10.97
swo 10.73
swo 9.46

sorw 16.69
sorw 17.01
sorw 16.40
sorw 15.48

sorwo 16.64
sorwo 14.63
sorwo 14.88
sorwo 14.38

sovw 15.12
sovw 14.51
sovw 12.93
sovw 11.93

sovwo 12.05
sovwo 11.85
sovwo 14.23
sovwo 15.05

sow 14.23
sow 12.60
sow 13.23
sow 13.10

sowo 14.08
sowo 14.13
sowo 12.33
sowo 12.96

run;

data study III day 14;
input trt $ wlost;
cards;

hvowo 33.02
hvowo 36.59
hvowo 40.52
hvowo 39.73

hvow 39.58
hvow 44.06
hvow 39.52
```

hvow 41.03

hw 34.49
hw 29.73
hw 30.86
hw 30.53

hwo 32.79
hwo 40.41
hwo 30.53
hwo 37.43

horw 43.11
horw 36.91
horw 33.37
horw 32.24

horwo 37.11
horwo 33.11
horwo 35.20
horwo 34.36

how 36.53
how 32.71
how 31.23
how 28.36

howo 35.58
howo 34.44
howo 32.25
howo 33.12

sw 46.97
sw 48.39
sw 45.12
sw 45.96

swo 40.17
swo 43.13
swo 40.08
swo 38.63

sorw 39.33
sorw 40.30
sorw 39.13
sorw 36.54

sorwo 40.43
sorwo 35.00
sorwo 34.78
sorwo 33.72

sovw 33.79
sovw 32.47
sovw 31.50
sovw 29.30

```
sovwo 26.31
sovwo 30.30
sovwo 32.37
sovwo 36.93

sow 33.90
sow 30.71
sow 31.82
sow 31.35

sowo 34.17
sowo 34.31
sowo 28.84
sowo 30.85

run;


data study III day15;
input trt $ wlost;
cards;

hvowo 40.62
hvowo 44.60
hvowo 47.72
hvowo 46.85

hvow 48.85
hvow 53.17
hvow 47.91
hvow 48.64

hw 40.55
hw 35.77
hw 36.83
hw 36.90

hwo 40.09
hwo 47.21
hwo 36.34
hwo 45.82

horw 52.60
horw 44.24
horw 39.89
horw 38.89

horwo 44.21
horwo 39.04
horwo 41.55
horwo 41.08

how 44.21
how 39.04
how 41.55
how 41.08
```

```
howo 42.52
howo 41.29
howo 39.31
howo 39.71

sw 53.08
sw 54.94
sw 51.87
sw 52.53

swo 45.34
swo 49.74
swo 45.05
swo 43.47

sorw 47.90
sorw 49.19
sorw 48.30
sorw 45.04

sorwo 49.39
sorwo 42.62
sorwo 42.20
sorwo 41.35

sovw 41.52
sovw 40.78
sovw 39.99
sovw 37.95

sovwo 32.20
sovwo 37.94
sovwo 40.03
sovwo 45.98

sow 41.46
sow 37.95
sow 39.54
sow 38.89

sowo 42.53
sowo 42.70
sowo 35.16
sowo 37.61

run;


data study III day16;
input trt $ wlost;
cards;

hvowo 55.39
hvowo 59.29
hvowo 61.39
hvowo 60.32
```

hvow 64.39
hvow 69.19
hvow 63.56
hvow 63.15

hw 87.18
hw 93.86
hw 98.26
hw 85.16

hwo 55.78
hwo 61.28
hwo 48.97
hwo 61.27

horw 69.67
horw 57.51
horw 52.35
horw 51.48

horwo 58.33
horwo 50.98
horwo 54.36
horwo 53.73

how 58.02
how 51.55
how 48.76
how 44.92

howo 56.08
howo 54.38
howo 51.03
howo 52.33

sw 75.37
sw 79.08
sw 75.26
sw 74.91

swo 65.81
swo 72.39
swo 65.68
swo 63.28

sorw 66.27
sorw 68.73
sorw 68.33
sorw 64.17

sorwo 68.41
sorwo 59.74
sorwo 59.68
sorwo 59.10

sovw 64.09
sovw 62.04

```
sovw 62.12
sovw 57.55

sovwo 49.07
sovwo 56.77
sovwo 59.75
sovwo 68.54

sow 57.84
sow 53.98
sow 55.81
sow 54.83

sowo 59.29
sowo 59.43
sowo 49.30
sowo 53.43

run;


data study III day17;
input trt $ wlost;
cards;

hvowo 71.12
hvowo 74.97
hvowo 76.20
hvowo 74.08

hvow 78.11
hvow 79.41
hvow 75.85
hvow 75.93

hw 69.61
hw 63.19
hw 63.94
hw 64.76

hwo 73.77
hwo 77.22
hwo 64.19
hwo 78.21

horw 80.67
horw 70.81
horw 65.25
horw 64.33

horwo 58.33
horwo 50.98
horwo 54.36
horwo53.73

how 71.13
how 64.46
```

```
how 61.05
how 55.35

howo 69.66
howo 68.03
howo 63.95
howo 65.16

sw 94.30
sw 99.12
sw 93.78
sw 92.95

swo 83.11
swo 90.58
swo 81.91
swo 78.89

sorw 80.45
sorw 80.75
sorw 81.40
sorw 78.23

sorwo 82.38
sorwo 74.92
sorwo 74.80
sorwo 74.60

sovw 82.16
sovw 79.89
sovw 80.68
sovw 72.59

sovwo 62.77
sovwo 73.44
sovwo 76.12
sovwo 88.00

sow 72.43
sow 67.91
sow 69.37
sow 69.10

sowo 73.78
sowo 74.14
sowo 62.27
sowo 67.05

run;


data study III day18;
input trt $ wlost;
cards;

hvowo 72.93
hvowo 104.70
```

```
hvowo 69.03
hvowo 67.10

hvow 80.16
hvow 80.80
hvow 78.27
hvow 77.59

hw 77.57
hw 72.68
hw 71.78
hw 73.44

hwo 80.37
hwo 79.66
hwo 79.86
hwo 78.69

horw 82.03
horw 73.07
horw 71.58
horw 71.73

horwo 76.25
horwo 70.91
horwo 74.07
horwo 75.10

how 74.03
how 71.17
how 67.46
how 58.78

howo 73.64
howo 73.19
howo 70.58
howo 71.34

sw 99.06
sw 99.64
sw 108.57
sw 95.25

swo 84.20
swo 88.49
swo 83.68
swo 81.13

sorw  80.67
sorw 91.10
sorw 95.55
sorw 83.69

sorwo 80.52
sorwo 76.19
sorwo 75.96
sorwo 75.61
```

```
sovw 84.21
sovw 82.05
sovw 80.81
sovw 71.16

sovwo 81.48
sovwo 76.28
sovwo 75.10
sovwo 75.63

sow 73.93
sow 69.86
sow 70.14
sow 70.99

sowo 73.94
sowo 74.61
sowo 66.95
sowo 70.32

run;


data study III day19;
input trt $ wlost;
cards;

hvowo 82.55
hvowo 83.75
hvowo 82.78
hvowo 82.42

hvow 83.98
hvow 84.23
hvow 82.25
hvow 81.62

hw 83.03
hw 80.42
hw 80.47
hw 81.21

hwo 85.18
hwo 87.16
hwo 82.56
hwo 87.11

horw 85.54
horw 77.36
horw 76.91
horw 77.60

horwo 80.44
horwo 77.69
horwo 79.38
horwo 81.72
```

```
how 78.32
how 77.11
how 73.70
how 62.64

howo 78.03
howo 78.02
howo 75.97
howo 76.83

sw 105.02
sw 103.99
sw 114.79
sw 103.21

swo 89.92
swo 92.54
swo 89.60
swo 88.79

sorw 83.96
sorw 95.69
sorw 100.00
sorw 88.02

sorwo 83.97
sorwo 80.48
sorwo 80.18
sorwo 79.77

sovw 91.97
sovw 88.13
sovw 86.80
sovw 75.42

sovwo 74.00
sovwo 78.04
sovwo 77.00
sovwo 72.40

sow 78.53
sow 74.57
sow 74.36
sow 75.38

sowo 77.98
sowo 78.63
sowo 73.63
sowo 75.70

run;

data study III day20;
input trt $ wlost;
cards;
```

hvowo 86.59
hvowo 87.62
hvowo 86.33
hvowo 86.22

hvow 87.56
hvow 87.57
hvow 85.90
hvow 85.30

hw 87.22
hw 85.51
hw 85.64
hw 86.20

hwo 89.13
hwo 90.63
hwo 87.64
hwo 90.52

horw 88.93
horw 81.56
horw 81.31
horw 82.32

horwo 84.35
horwo 82.77
horwo 83.77
horwo 81.69

how 82.34
how 82.23
how 79.08
how 66.18

howo 82.05
howo 82.95
howo 80.57
howo 81.52

sw 108.47
sw 106.24
sw 118.26
sw 107.20

swo 93.24
swo 94.63
swo 92.91
swo 92.96

sorw 86.44
sorw 85.35
sorw 86.17
sorw 83.44

sorwo 87.24
sorwo 84.21

```
sorwo 83.96
sorwo 83.52

sovw 97.98
sovw 93.36
sovw 91.98
sovw 79.39

sovwo 78.78
sovwo 81.84
sovwo 80.86
sovwo 87.03

sow 82.67
sow 78.68
sow 78.41
sow 79.36

sowo 82.76
sowo 82.37
sowo 78.92
sowo 80.43

run;

data study III day21;
input trt $ wlost;
cards;

hvowo 89.26
hvowo 90.32
hvowo 88.95
hvowo 88.89

hvow 90.02
hvow 89.92
hvow 88.55
hvow 87.97

hw 90.07
hw 88.74
hw 88.93
hw 89.41

hwo 89.13
hwo 90.63
hwo 87.34
hwo 90.52

horw 91.40
horw 84.65
horw 84.50
horw 85.69

horwo 87.08
horwo 86.06
horwo 86.75
```

```
horwo 90.26

how 85.37
how 86.00
how 82.89
how 68.84

howo 85.13
howo 85.49
howo 83.86
howo 84.80

sw 108.97
sw 106.12
sw 118.78
sw 108.61

swo 93.72
swo 94.52
swo 93.41
swo 93.83

sorw 88.81
sorw 87.97
sorw 88.81
sorw 85.90

sorwo 89.54
sorwo 86.68
sorwo 86.57
sorwo 86.10

sovw 101.50
sovw 96.66
sovw 95.31
sovw 81.81

sovwo #value!
sovwo 84.25
sovwo 83.27
sovwo 99.94

sow 85.59
sow 81.55
sow 81.48
sow 82.16

sowo 84.86
sowo 85.10
sowo 82.42
sowo 83.66

run;

data study III day22;
input trt $ wlost;
cards;
```

hvowo 90.89
hvowo 91.96
hvowo 90.57
hvowo 90.59

hvow 91.52
hvow 91.47
hvow 90.16
hvow 87.97

hw 91.77
hw 90.63
hw 90.83
hw 91.22

hwo 93.28
hwo 94.33
hwo 91.94
hwo 94.25

horw 92.93
horw 86.62
horw 86.39
horw 87.69

horwo 88.75
horwo 88.01
horwo 88.60
horwo 92.28

how 87.08
how 88.36
how 85.23
how 69.82

howo 87.05
howo 87.46
howo 85.92
howo 86.85

sw 160.56
sw 110.84
sw 144.10
sw 107.73

swo 93.36
swo 94.16
swo 93.18
swo 93.60

sorw 90.34
sorw 89.61
sorw 90.44
sorw 87.50

sorwo 90.98

```
sorwo 88.24
sorwo 88.23
sorwo 87.68

sovw 103.44
sovw 98.71
sovw 97.35
sovw 83.35

sovwo #value!
sovwo 85.74
sovwo 84.71
sovwo 101.66

sow 87.45
sow 83.48
sow 83.53
sow 84.00

sowo 86.78
sowo 86.87
sowo 84.62
sowo 85.72

run;


data study III day23;
input trt $ wlost;
cards;

hvowo 92.05
hvowo 93.24
hvowo 91.69
hvowo 91.90

hvow 92.61
hvow 92.60
hvow 91.39
hvow 90.92

hw 92.93
hw 92.01
hw 92.16
hw 92.44

hwo 94.05
hwo 94.99
hwo 92.99
hwo 94.79

horw 94.09
horw 88.37
horw 88.00
horw 89.39

horwo 90.19
```

```
horwo 89.67
horwo 90.12
horwo 93.96

how 88.93
how 90.46
how 71.93
how 69.82

howo 88.71
howo 89.16
howo 87.69
howo 88.63

sw 160.66
sw 112.64
sw 145.49
sw 109.09

swo 92.32
swo 92.92
swo 92.09
swo 92.49

sorw 91.36
sorw 90.77
sorw 91.58
sorw 88.63

sorwo 91.91
sorwo 89.34
sorwo 89.34
sorwo 88.78

sovw 103.54
sovw 100.09
sovw 98.54
sovw 84.31

sovwo #VALUE!
sovwo 86.21
sovwo 85.33
sovwo 102.44

sow 89.07
sow 85.10
sow 85.30
sow 85.47

sowo 88.36
sowo 88.38
sowo 86.34
sowo 87.39

run;

data study III day24;
```

```
input trt $ wlost;
cards;

hvowo 94.58
hvowo 95.82
hvowo 94.16
hvowo 94.36

hvow 95.21
hvow 93.00
hvow 91.45
hvow 91.02

hw 95.55
hw 94.81
hw 94.95
hw 95.16

hwo 95.68
hwo 96.57
hwo 95.44
hwo 96.48

horw 96.62
horw 91.20
horw 90.66
horw 92.12

horwo 92.69
horwo 92.26
horwo 92.76
horwo 96.78

how 94.89
how 96.82
how 94.49
how 74.14

howo 91.37
howo 91.80
howo 90.38
howo 91.30

sw 162.62
sw 116.67
sw 149.45
sw 112.41

swo 94.06
swo 94.87
swo 93.88
swo 94.12

sorw 93.74
sorw 93.45
sorw 94.25
sorw 91.25
```

```
sorwo 94.28
sorwo 91.84
sorwo 91.90
sorwo 91.34

sovw 105.44
sovw 103.17
sovw 101.94
sovw 86.67

sovwo #VALUE!
sovwo 87.78
sovwo 86.98
sovwo 104.53

sow 91.70
sow 87.84
sow 88.04
sow 88.00

sowo 90.93
sowo 90.85
sowo 89.02
sowo 90.08

run;


data study III day25;
input trt $ wlost;
cards;

hvowo 97.14
hvowo 98.52
hvowo 96.72
hvowo 96.93

hvow 98.06
hvow 97.70
hvow #value!
hvow 96.13

hw 98.23
hw 97.39
hw 97.72
hw 97.70

hwo 97.73
hwo 98.06
hwo 97.30
hwo 97.93

horw 99.32
horw 94.69
horw 93.71
horw 95.22
```

horwo 95.84
horwo 95.07
horwo 95.91
horwo 99.66

how 94.89
how 96.82
how 94.49
how 78.33

howo 94.77
howo 95.45
howo 93.58
howo 94.47

sw 158.61
sw 116.18
sw 142.44
sw 113.06

swo 95.55
swo 96.50
swo 95.52
swo 96.53

sorw 96.98
sorw 97.04
sorw 97.58
sorw 95.45

sorwo 97.57
sorwo 95.24
sorwo 95.32
sorwo 95.05

sovw 105.39
sovw 104.85
sovw 103.80
sovw 90.50

sovwo #VALUE!
sovwo 90.62
sovwo 90.75
sovwo 105.00

sow 95.50
sow 91.93
sow 93.42
sow 92.63

sowo 95.50
sowo 95.22
sowo 92.81
sowo 95.91

```
run;
```

```
;
proc anova;
class trt wlost;
model wlost=trt;
means trt/Tukey Duncan;
title "comparison of percent of water losses on Jan. 14";
run;
```

```
;
proc anova;
class trt wlost;
model wlost=trt;
means trt/Tukey Duncan;
title "comparison of percent of water losses on Jan. 14";
run;
```

## 2000 and 2001 Seasonal Averages – Study II - Bowling Green 2000 Climate

...CLIMATIC SUMMARY FOR 2000 FOR BOWLING GREEN KENTUCKY...

| MONTH | HIGHEST | LOWEST | MEAN | DEPARTURE | PCPN | DEPARTURE | SNOWFALL |
|---|---|---|---|---|---|---|---|
| JANUARY | 70 | 11 | 35.8 | PLUS 2.9 | 3.04 | MINUS 0.78 | 1.3 |
| FEBRUARY | 75 | 17 | 44.5 | PLUS 7.3 | 3.44 | MINUS 0.69 | T |
| MARCH | 78 | 26 | 50.1 | PLUS 2.7 | 2.71 | MINUS 2.39 | T |
| APRIL | 78 | 27 | 55.2 | MINUS 1.8 | 4.87 | PLUS 0.55 | 0 |
| MAY | 87 | 42 | 67.9 | MINUS 2.1 | 5.94 | PLUS 1.00 | 0 |
| JUNE | 94 | 46 | 74.3 | PLUS 0.1 | 1.59 | MINUS 2.58 | 0 |
| JULY | 97 | 55 | 77.4 | MINUS 0.5 | 1.76 | MINUS 2.98 | 0 |
| AUGUST | 98 | 57 | 77.9 | PLUS 1.6 | 3.85 | PLUS 0.34 | 0 |
| SEPTEMBER | 90 | 40 | 68.6 | MINUS 1.1 | 4.67 | PLUS 0.95 | 0 |
| OCTOBER | 87 | 29 | 61.1 | PLUS 3.3 | 0.65 | MINUS 2.37 | 0 |
| NOVEMBER | 83 | 17 | 45.4 | MINUS 2.1 | 3.49 | MINUS 0.94 | 0 |
| DECEMBER | 58 | 4 | 27.5 | MINUS 10.3 | 2.50 | MINUS 1.90 | E1.9 |
| ANNUAL | 98 | 4 | 57.1 | NORMAL | 38.49 | MINUS 12.60 | E1.9 |

DEGREE DAY DATA...

| MONTH | HEATING | DEPARTURE | COOLING | DEPARTURE |
|---|---|---|---|---|
| JANUARY | 895 | MINUS 100 | 0 | NORMAL |
| FEBRUARY | 589 | MINUS 189 | 1 | PLUS 1 |
| MARCH | 455 | MINUS 96 | 0 | NORMAL |
| APRIL | 290 | PLUS 37 | 3 | MINUS 10 |
| MAY | 36 | MINUS 59 | 133 | PLUS 13 |
| JUNE | 6 | PLUS 6 | 287 | PLUS 11 |
| JULY | 0 | NORMAL | 390 | MINUS 10 |
| AUGUST | 0 | NORMAL | 392 | PLUS 42 |
| SEPTEMBER | 61 | PLUS 24 | 176 | MINUS 2 |
| OCTOBER | 171 | MINUS 80 | 56 | PLUS 29 |
| NOVEMBER | 590 | PLUS 65 | 7 | PLUS 7 |
| DECEMBER | 1157 | PLUS 314 | 0 | NORMAL |
| ANNUAL | 4250 | MINUS 78 | 1445 | PLUS 81 |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**January 2001**

| | Temperature | | | | Degree Days | | Precipitation | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 27 | 17 | 22 | -12 | 0 | 43 | .06 | T | T |
| 2 | 25 | 9 | 17 | -17 | 0 | 48 | T | T | T |
| 3 | 29 | 3 | 16 | -18 | 0 | 49 | 0.00 | 0.0 | T |
| 4 | 36 | 18 | 27 | -6 | 0 | 38 | 0.00 | 0.0 | 0. |
| 5 | 47 | 31 | 39 | +6 | 0 | 26 | 0.00 | 0.0 | 0. |
| 6 | 46 | 21 | 34 | +1 | 0 | 31 | 0.00 | 0.0 | 0. |
| 7 | 52 | 30 | 41 | +8 | 0 | 24 | 0.00 | 0.0 | 0. |
| 8 | 35 | 23 | 29 | -4 | 0 | 36 | T | T | T |
| 9 | 35 | 20 | 28 | -5 | 0 | 37 | T | T | T |
| 10 | 43 | 15 | 29 | -4 | 0 | 36 | 0.00 | 0.0 | 0. |
| 11 | 42 | 19 | 31 | -2 | 0 | 34 | .07 | 0.0 | 0. |
| 12 | 43 | 33 | 38 | +5 | 0 | 27 | .06 | .6 | T |
| 13 | 41 | 28 | 35 | +2 | 0 | 30 | 0.00 | 0.0 | 0. |
| 14 | 50 | 28 | 39 | +7 | 0 | 26 | .02 | 0.0 | 0. |
| 15 | 50 | 32 | 41 | +9 | 0 | 24 | 0.00 | 0.0 | 0. |
| 16 | 41 | 28 | 35 | +3 | 0 | 30 | 0.00 | 0.0 | 0. |
| 17 | 42 | 28 | 35 | +3 | 0 | 30 | .01 | T | 0. |
| 18 | 41 | 36 | 39 | +7 | 0 | 26 | .50 | 0.0 | 0. |
| 19 | 40 | 32 | 36 | +4 | 0 | 29 | .45 | 1.2 | 0. |
| 20 | 32 | 21 | 27 | -5 | 0 | 38 | .02 | .2 | |
| 21 | 30 | 13 | 22 | -11 | 0 | 43 | 0.00 | 0.0 | |
| 22 | 42 | 20 | 31 | -2 | 0 | 34 | 0.00 | 0.0 | |
| 23 | 46 | 19 | 33 | +0 | 0 | 32 | 0.00 | 0.0 | |
| 24 | 49 | 26 | 38 | +5 | 0 | 27 | 0.00 | 0.0 | 0. |
| 25 | 38 | 19 | 29 | -4 | 0 | 36 | 0.00 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 26 | 42 | 17 | 30 | -3 | 0 | 35 | .01 | 0.0 | 0. |
| 27 | 41 | 21 | 31 | -2 | 0 | 34 | 0.00 | 0.0 | 0. |
| 28 | 43 | 19 | 31 | -2 | 0 | 34 | 0.00 | 0.0 | 0. |
| 29 | 63 | 32 | 48 | +15 | 0 | 17 | .56 | 0.0 | 0. |
| 30 | 62 | 44 | 53 | +20 | 0 | 12 | .01 | 0.0 | 0. |
| 31 | 45 | 36 | 41 | +7 | 0 | 24 | .01 | 0.0 | 0. |
| TOTALS | | | | | 0 | 990 | 1.78 | 2.0 | |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**February 2001**

| | -----Temperature------ | | | | ---Degree Days-- | | -----Precipitation----- | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 48 | 33 | 41 | +7 | 0 | 24 | 0.00 | 0.0 | 0. |
| 2 | 35 | 17 | 26 | -8 | 0 | 39 | 0.00 | 0.0 | 0. |
| 3 | 45 | 14 | 30 | -4 | 0 | 35 | 0.00 | 0.0 | 0. |
| 4 | 46 | 27 | 37 | +3 | 0 | 28 | .01 | 0.0 | 0. |
| 5 | 42 | 26 | 34 | -1 | 0 | 31 | T | 0.0 | 0. |
| 6 | 62 | 25 | 44 | +9 | 0 | 21 | 0.00 | 0.0 | 0. |
| 7 | 66 | 43 | 55 | +20 | 0 | 10 | 0.00 | 0.0 | 0. |
| 8 | 70 | 51 | 61 | +26 | 0 | 4 | 0.00 | 0.0 | 0. |
| 9 | 69 | 34 | 52 | +17 | 0 | 13 | .62 | 0.0 | 0. |
| 10 | 37 | 26 | 32 | -4 | 0 | 33 | 0.00 | 0.0 | 0. |
| 11 | 41 | 21 | 31 | -5 | 0 | 34 | T | 0.0 | 0. |
| 12 | 48 | 38 | 43 | +7 | 0 | 22 | T | 0.0 | 0. |
| 13 | 54 | 45 | 50 | +13 | 0 | 15 | .10 | 0.0 | 0. |
| 14 | 64 | 53 | 59 | +22 | 0 | 6 | 1.32 | 0.0 | 0. |
| 15 | 60 | 52 | 56 | +19 | 0 | 9 | .57 | 0.0 | 0. |
| 16 | 52 | 32 | 42 | +5 | 0 | 23 | .68 | 0.0 | 0. |
| 17 | 34 | 22 | 28 | -10 | 0 | 37 | 0.00 | 0.0 | 0. |
| 18 | 36 | 19 | 28 | -10 | 0 | 37 | 0.00 | 0.0 | 0. |
| 19 | 60 | 24 | 42 | +4 | 0 | 23 | 0.00 | 0.0 | 0. |
| 20 | 63 | 36 | 50 | +11 | 0 | 15 | .07 | 0.0 | 0. |
| 21 | 49 | 33 | 41 | +2 | 0 | 24 | .33 | 0.0 | 0. |
| 22 | 35 | 32 | 34 | -5 | 0 | 31 | .26 | 0.0 | 0. |
| 23 | 47 | 32 | 40 | +0 | 0 | 25 | 0.00 | 0.0 | 0. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 24 | 69 | 39 | 54 | +14 | 0 | 11 | .06 | 0.0 |
| 0. | | | | | | | | |
| 25 | 67 | 42 | 55 | +15 | 0 | 10 | .47 | 0.0 |
| 0. | | | | | | | | |
| 26 | 56 | 30 | 43 | +2 | 0 | 22 | 0.00 | 0.0 |
| 0. | | | | | | | | |
| 27 | 50 | 31 | 41 | +0 | 0 | 24 | 0.00 | 0.0 |
| 0. | | | | | | | | |
| 28 | 49 | 33 | 41 | -1 | 0 | 24 | T | 0.0 |
| 0. | | | | | | | | |
| | | | | | ------- | ------- | ------ | -------- |
| TOTALS | | | | | 0 | 630 | 4.49 | 0.0 |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**March 2001**

| | -----Temperature------ | | | | ---Degree Days-- | | -----Precipitation----- | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 53 | 26 | 40 | -2 | 0 | 25 | T | 0.0 | 0. |
| 2 | 55 | 38 | 47 | +5 | 0 | 18 | T | 0.0 | 0. |
| 3 | 53 | 37 | 45 | +3 | 0 | 20 | .09 | 0.0 | 0. |
| 4 | 46 | 36 | 41 | -2 | 0 | 24 | 1.17 | 0.0 | 0. |
| 5 | 41 | 30 | 36 | -7 | 0 | 29 | 0.00 | 0.0 | 0. |
| 6 | 43 | 27 | 35 | -9 | 0 | 30 | 0.00 | 0.0 | 0. |
| 7 | 50 | 25 | 38 | -6 | 0 | 27 | 0.00 | 0.0 | 0. |
| 8 | 54 | 27 | 41 | -4 | 0 | 24 | 0.00 | 0.0 | 0. |
| 9 | 47 | 25 | 36 | -9 | 0 | 29 | 0.00 | 0.0 | 0. |
| 10 | 55 | 20 | 38 | -7 | 0 | 27 | 0.00 | 0.0 | 0. |
| 11 | 66 | 27 | 47 | +1 | 0 | 18 | 0.00 | 0.0 | 0. |
| 12 | 62 | 36 | 49 | +3 | 0 | 16 | .04 | 0.0 | 0. |
| 13 | 64 | 44 | 54 | +7 | 0 | 11 | .32 | 0.0 | 0. |
| 14 | 61 | 32 | 47 | +0 | 0 | 18 | 0.00 | 0.0 | 0. |
| 15 | 54 | 47 | 51 | +4 | 0 | 14 | .46 | 0.0 | 0. |
| 16 | 52 | 41 | 47 | -1 | 0 | 18 | .01 | 0.0 | 0. |
| 17 | 41 | 37 | 39 | -9 | 0 | 26 | 0.00 | 0.0 | 0. |
| 18 | 53 | 29 | 41 | -7 | 0 | 24 | 0.00 | 0.0 | 0. |
| 19 | 60 | 31 | 46 | -3 | 0 | 19 | T | 0.0 | 0. |
| 20 | 49 | 41 | 45 | -4 | 0 | 20 | .51 | 0.0 | 0. |
| 21 | 60 | 40 | 50 | +1 | 0 | 15 | .02 | 0.0 | 0. |
| 22 | 62 | 35 | 49 | -1 | 0 | 16 | 0.00 | 0.0 | 0. |
| 23 | 66 | 33 | 50 | +0 | 0 | 15 | 0.00 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 53 | 33 | 43 | -7 | 0 | 22 | 0.00 | 0.0 | 0. |
| 25 | 45 | 28 | 37 | -14 | 0 | 28 | 0.00 | 0.0 | 0. |
| 26 | 42 | 24 | 33 | -18 | 0 | 32 | 0.00 | 0.0 | 0. |
| 27 | 48 | 20 | 34 | -17 | 0 | 31 | 0.00 | 0.0 | 0. |
| 28 | 58 | 21 | 40 | -11 | 0 | 25 | T | 0.0 | 0. |
| 29 | 59 | 44 | 52 | +0 | 0 | 13 | .03 | 0.0 | 0. |
| 30 | 53 | 38 | 46 | -6 | 0 | 19 | .26 | 0.0 | 0. |
| 31 | 55 | 45 | 50 | -2 | 0 | 15 | .17 | 0.0 | 0. |
| TOTALS | | | | | 0 | 668 | 3.08 | 0.0 | |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**April 2001**

| | Temperature | | | | Degree Days | | Precipitation | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 54 | 36 | 45 | -8 | 0 | 20 | .14 | 0.0 | 0. |
| 2 | 60 | 44 | 52 | -1 | 0 | 13 | .37 | 0.0 | 0. |
| 3 | 67 | 50 | 59 | +6 | 0 | 6 | .30 | 0.0 | 0. |
| 4 | 71 | 46 | 59 | +5 | 0 | 6 | 0.00 | 0.0 | 0. |
| 5 | 74 | 49 | 62 | +8 | 0 | 3 | 0.00 | 0.0 | 0. |
| 6 | 85 | 62 | 74 | +20 | 9 | 0 | 0.00 | 0.0 | 0. |
| 7 | 88 | 68 | 78 | +23 | 13 | 0 | 0.00 | 0.0 | 0. |
| 8 | 84 | 66 | 75 | +20 | 10 | 0 | 0.00 | 0.0 | 0. |
| 9 | 84 | 67 | 76 | +21 | 11 | 0 | 0.00 | 0.0 | 0. |
| 10 | 87 | 64 | 76 | +21 | 11 | 0 | T | 0.0 | 0. |
| 11 | 85 | 69 | 77 | +21 | 12 | 0 | 0.00 | 0.0 | 0. |
| 12 | 81 | 62 | 72 | +16 | 7 | 0 | .16 | 0.0 | 0. |
| 13 | 74 | 54 | 64 | +8 | 0 | 1 | .23 | 0.0 | 0. |
| 14 | 75 | 47 | 61 | +4 | 0 | 4 | 0.00 | 0.0 | 0. |
| 15 | 73 | 50 | 62 | +5 | 0 | 3 | .39 | 0.0 | 0. |
| 16 | 60 | 44 | 52 | -5 | 0 | 13 | T | 0.0 | 0. |
| 17 | 46 | 33 | 40 | -17 | 0 | 25 | T | T | 0. |
| 18 | 58 | 33 | 46 | -12 | 0 | 19 | 0.00 | 0.0 | 0. |
| 19 | 69 | 32 | 51 | -7 | 0 | 14 | 0.00 | 0.0 | 0. |
| 20 | 69 | 52 | 61 | +2 | 0 | 4 | .13 | 0.0 | 0. |
| 21 | 78 | 63 | 71 | +12 | 6 | 0 | 0.00 | 0.0 | 0. |
| 22 | 83 | 62 | 73 | +14 | 8 | 0 | 0.00 | 0.0 | 0. |
| 23 | 82 | 61 | 72 | +13 | 7 | 0 | .37 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 66 | 47 | 57 | -2 | 0 | 8 | 0.00 | 0.0 | 0. |
| 25 | 65 | 40 | 53 | -7 | 0 | 12 | 0.00 | 0.0 | 0. |
| 26 | 71 | 36 | 54 | -6 | 0 | 11 | 0.00 | 0.0 | 0. |
| 27 | 83 | 42 | 63 | +3 | 0 | 2 | 0.00 | 0.0 | 0. |
| 28 | 77 | 49 | 63 | +3 | 0 | 2 | 0.00 | 0.0 | 0. |
| 29 | 79 | 45 | 62 | +1 | 0 | 3 | 0.00 | 0.0 | 0. |
| 30 | 84 | 48 | 66 | +5 | 1 | 0 | 0.00 | 0.0 | 0. |
| | | | | | ------- | ------- | ------ | -------- | |
| TOTALS | | | | | 95 | 169 | 2.09 | T | |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**May 2001**

| | -----Temperature------ | | | | ---Degree Days-- | | -----Precipitation----- | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| ---- | --- | --- | ---- | ------ | ------- | ------- | ------ | -------- | ----- |
| 1 | 81 | 55 | 68 | +7 | 3 | 0 | T | 0.0 | 0. |
| 2 | 82 | 51 | 67 | +5 | 2 | 0 | 0.00 | 0.0 | 0. |
| 3 | 83 | 54 | 69 | +7 | 4 | 0 | 0.00 | 0.0 | 0. |
| 4 | 85 | 52 | 69 | +7 | 4 | 0 | 0.00 | 0.0 | 0. |
| 5 | 86 | 56 | 71 | +8 | 6 | 0 | 0.00 | 0.0 | 0. |
| 6 | 87 | 63 | 75 | +12 | 10 | 0 | T | 0.0 | 0. |
| 7 | 80 | 60 | 70 | +7 | 5 | 0 | 1.33 | 0.0 | 0. |
| 8 | 76 | 59 | 68 | +5 | 3 | 0 | T | 0.0 | 0. |
| 9 | 77 | 57 | 67 | +3 | 2 | 0 | T | 0.0 | 0. |
| 10 | 80 | 56 | 68 | +4 | 3 | 0 | .01 | 0.0 | 0. |
| 11 | 84 | 57 | 71 | +7 | 6 | 0 | .43 | 0.0 | 0. |
| 12 | 75 | 52 | 64 | -1 | 0 | 1 | 0.00 | 0.0 | 0. |
| 13 | 74 | 48 | 61 | -4 | 0 | 4 | 0.00 | 0.0 | 0. |
| 14 | 76 | 48 | 62 | -3 | 0 | 3 | 0.00 | 0.0 | 0. |
| 15 | 87 | 57 | 72 | +7 | 7 | 0 | 0.00 | 0.0 | 0. |
| 16 | 88 | 65 | 77 | +11 | 12 | 0 | 0.00 | 0.0 | 0. |
| 17 | 88 | 68 | 78 | +12 | 13 | 0 | 0.00 | 0.0 | 0. |
| 18 | 88 | 71 | 80 | +14 | 15 | 0 | T | 0.0 | 0. |
| 19 | 81 | 68 | 75 | +8 | 10 | 0 | .03 | 0.0 | 0. |
| 20 | 82 | 64 | 73 | +6 | 8 | 0 | .04 | 0.0 | 0. |
| 21 | 79 | 60 | 70 | +3 | 5 | 0 | 1.81 | 0.0 | 0. |
| 22 | 71 | 50 | 61 | -7 | 0 | 4 | .30 | 0.0 | 0. |
| 23 | 71 | 49 | 60 | -8 | 0 | 5 | .07 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 69 | 53 | 61 | -7 | 0 | 4 | .01 | 0.0 | 0. |
| 25 | 69 | 50 | 60 | -9 | 0 | 5 | 0.00 | 0.0 | 0. |
| 26 | 77 | 56 | 67 | -2 | 2 | 0 | 0.00 | 0.0 | 0. |
| 27 | 77 | 59 | 68 | -1 | 3 | 0 | T | 0.0 | 0. |
| 28 | 77 | 55 | 66 | -3 | 1 | 0 | 0.00 | 0.0 | 0. |
| 29 | 79 | 52 | 66 | -4 | 1 | 0 | 0.00 | 0.0 | 0. |
| 30 | 80 | 53 | 67 | -3 | 2 | 0 | .02 | 0.0 | 0. |
| 31 | 79 | 58 | 69 | -1 | 4 | 0 | .98 | 0.0 | 0. |
| TOTALS | | | | | 131 | 26 | 5.03 | 0.0 | |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**June 2001**

| | -----Temperature------ | | | | ---Degree Days-- | | -----Precipitation----- | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 69 | 52 | 61 | -10 | 0 | 4 | .01 | 0.0 | 0. |
| 2 | 77 | 55 | 66 | -5 | 1 | 0 | .24 | 0.0 | 0. |
| 3 | 68 | 49 | 59 | -13 | 0 | 6 | .12 | 0.0 | 0. |
| 4 | 87 | 61 | 74 | +2 | 9 | 0 | .41 | 0.0 | 0. |
| 5 | 87 | 63 | 75 | +3 | 10 | 0 | 0.00 | 0.0 | 0. |
| 6 | 87 | 67 | 77 | +5 | 12 | 0 | .64 | 0.0 | 0. |
| 7 | 82 | 69 | 76 | +4 | 11 | 0 | T | 0.0 | 0. |
| 8 | 82 | 65 | 74 | +1 | 9 | 0 | T | 0.0 | 0. |
| 9 | 82 | 61 | 72 | -1 | 7 | 0 | 0.00 | 0.0 | 0. |
| 10 | 83 | 55 | 69 | -4 | 4 | 0 | 0.00 | 0.0 | 0. |
| 11 | 87 | 59 | 73 | +0 | 8 | 0 | 0.00 | 0.0 | 0. |
| 12 | 89 | 63 | 76 | +2 | 11 | 0 | 0.00 | 0.0 | 0. |
| 13 | 91 | 67 | 79 | +5 | 14 | 0 | 0.00 | 0.0 | 0. |
| 14 | 93 | 68 | 81 | +7 | 16 | 0 | 0.00 | 0.0 | 0. |
| 15 | 88 | 68 | 78 | +4 | 13 | 0 | .56 | 0.0 | 0. |
| 16 | 85 | 63 | 74 | -1 | 9 | 0 | 0.00 | 0.0 | 0. |
| 17 | 90 | 63 | 77 | +2 | 12 | 0 | 0.00 | 0.0 | 0. |
| 18 | 91 | 62 | 77 | +2 | 12 | 0 | 0.00 | 0.0 | 0. |
| 19 | 92 | 63 | 78 | +3 | 13 | 0 | 0.00 | 0.0 | 0. |
| 20 | 89 | 68 | 79 | +4 | 14 | 0 | 0.00 | 0.0 | 0. |
| 21 | 91 | 68 | 80 | +5 | 15 | 0 | .82 | 0.0 | 0. |
| 22 | 77 | 61 | 69 | -7 | 4 | 0 | 0.00 | 0.0 | 0. |
| 23 | 82 | 58 | 70 | -6 | 5 | 0 | 0.00 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 83 | 59 | 71 | -5 | 6 | 0 | 0.00 | 0.0 | 0. |
| 25 | 85 | 59 | 72 | -4 | 7 | 0 | T | 0.0 | 0. |
| 26 | 82 | 60 | 71 | -5 | 6 | 0 | 0.00 | 0.0 | 0. |
| 27 | 84 | 60 | 72 | -4 | 7 | 0 | .09 | 0.0 | 0. |
| 28 | 79 | 59 | 69 | -7 | 4 | 0 | .12 | 0.0 | 0. |
| 29 | 84 | 63 | 74 | -3 | 9 | 0 | .30 | 0.0 | 0. |
| 30 | 86 | 65 | 76 | -1 | 11 | 0 | .40 | 0.0 | 0. |
| TOTALS | | | | | 259 | 10 | 3.71 | 0.0 | |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**July 2001**

| | -----Temperature------ | | | | ---Degree Days-- | | -----Precipitation----- | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 87 | 67 | 77 | +0 | 12 | 0 | 0.00 | 0.0 | 0. |
| 2 | 83 | 66 | 75 | -2 | 10 | 0 | 0.00 | 0.0 | 0. |
| 3 | 91 | 66 | 79 | +2 | 14 | 0 | 0.00 | 0.0 | 0. |
| 4 | 89 | 72 | 81 | +3 | 16 | 0 | .01 | 0.0 | 0. |
| 5 | 87 | 66 | 77 | -1 | 12 | 0 | .31 | 0.0 | 0. |
| 6 | 83 | 62 | 73 | -5 | 8 | 0 | 0.00 | 0.0 | 0. |
| 7 | 92 | 60 | 76 | -2 | 11 | 0 | 0.00 | 0.0 | 0. |
| 8 | 96 | 77 | 87 | +9 | 22 | 0 | 0.00 | 0.0 | 0. |
| 9 | 89 | 74 | 82 | +4 | 17 | 0 | .29 | 0.0 | 0. |
| 10 | 92 | 72 | 82 | +4 | 17 | 0 | 0.00 | 0.0 | 0. |
| 11 | 91 | 67 | 79 | +1 | 14 | 0 | 0.00 | 0.0 | 0. |
| 12 | 81 | 60 | 71 | -7 | 6 | 0 | T | 0.0 | 0. |
| 13 | 85 | 60 | 73 | -5 | 8 | 0 | 0.00 | 0.0 | 0. |
| 14 | 85 | 56 | 71 | -7 | 6 | 0 | 0.00 | 0.0 | 0. |
| 15 | 87 | 56 | 72 | -6 | 7 | 0 | 0.00 | 0.0 | 0. |
| 16 | 91 | 58 | 75 | -3 | 10 | 0 | 0.00 | 0.0 | 0. |
| 17 | 91 | 70 | 81 | +3 | 16 | 0 | 0.00 | 0.0 | 0. |
| 18 | 86 | 70 | 78 | +0 | 13 | 0 | 1.10 | 0.0 | 0. |
| 19 | 90 | 72 | 81 | +3 | 16 | 0 | 0.00 | 0.0 | 0. |
| 20 | 85 | 73 | 79 | +1 | 14 | 0 | .79 | 0.0 | 0. |
| 21 | 88 | 70 | 79 | +1 | 14 | 0 | 0.00 | 0.0 | 0. |
| 22 | 90 | 71 | 81 | +3 | 16 | 0 | .02 | 0.0 | 0. |
| 23 | 93 | 74 | 84 | +6 | 19 | 0 | 0.00 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 93 | 74 | 84 | +6 | 19 | 0 | 0.00 | 0.0 | 0. |
| 25 | 93 | 72 | 83 | +5 | 18 | 0 | T | 0.0 | 0. |
| 26 | 83 | 74 | 79 | +1 | 14 | 0 | .41 | 0.0 | 0. |
| 27 | 86 | 73 | 80 | +2 | 15 | 0 | .01 | 0.0 | 0. |
| 28 | 87 | 75 | 81 | +3 | 16 | 0 | .59 | 0.0 | 0. |
| 29 | 89 | 76 | 83 | +5 | 18 | 0 | T | 0.0 | 0. |
| 30 | 92 | 72 | 82 | +4 | 17 | 0 | 0.00 | 0.0 | 0. |
| 31 | 92 | 70 | 81 | +3 | 16 | 0 | 0.00 | 0.0 | 0. |
| | | | | | ------- | ------- | ------ | -------- | |
| TOTALS | | | | | 431 | 0 | 3.53 | 0.0 | |

**Preliminary Local Climatological Data**
**Bowling Green Airport, (BWG), Bowling Green, KY**
**August 2001**

| | -----Temperature------ | | | | ---Degree Days-- | | -----Precipitation----- | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Max | Min | Mean | Depart | Cooling | Heating | Liquid | Snowfall | Depth |
| 1 | 92 | 70 | 81 | +3 | 16 | 0 | 0.00 | 0.0 | 0. |
| 2 | 92 | 72 | 82 | +4 | 17 | 0 | 0.00 | 0.0 | 0. |
| 3 | 86 | 73 | 80 | +2 | 15 | 0 | 1.32 | 0.0 | 0. |
| 4 | 89 | 73 | 81 | +3 | 16 | 0 | 0.00 | 0.0 | 0. |
| 5 | 90 | 70 | 80 | +2 | 15 | 0 | 0.00 | 0.0 | 0. |
| 6 | 90 | 71 | 81 | +3 | 16 | 0 | 0.00 | 0.0 | 0. |
| 7 | 90 | 72 | 81 | +4 | 16 | 0 | 0.00 | 0.0 | 0. |
| 8 | 91 | 72 | 82 | +5 | 17 | 0 | 0.00 | 0.0 | 0. |
| 9 | 88 | 74 | 81 | +4 | 16 | 0 | 1.13 | 0.0 | 0. |
| 10 | 88 | 74 | 81 | +4 | 16 | 0 | 0.00 | 0.0 | 0. |
| 11 | 88 | 72 | 80 | +3 | 15 | 0 | 0.00 | 0.0 | 0. |
| 12 | 88 | 69 | 79 | +2 | 14 | 0 | 0.00 | 0.0 | 0. |
| 13 | 87 | 69 | 78 | +1 | 13 | 0 | 0.00 | 0.0 | 0. |
| 14 | 85 | 66 | 76 | -1 | 11 | 0 | 0.00 | 0.0 | 0. |
| 15 | 88 | 62 | 75 | -2 | 10 | 0 | 0.00 | 0.0 | 0. |
| 16 | 87 | 68 | 78 | +2 | 13 | 0 | 0.00 | 0.0 | 0. |
| 17 | 85 | 62 | 74 | -2 | 9 | 0 | 0.00 | 0.0 | 0. |
| 18 | 87 | 67 | 77 | +1 | 12 | 0 | 0.00 | 0.0 | 0. |
| 19 | 83 | 64 | 74 | -2 | 9 | 0 | .03 | 0.0 | 0. |
| 20 | 82 | 58 | 70 | -6 | 5 | 0 | 0.00 | 0.0 | 0. |
| 21 | 85 | 54 | 70 | -6 | 5 | 0 | 0.00 | 0.0 | 0. |
| 22 | 93 | 63 | 78 | +2 | 13 | 0 | 0.00 | 0.0 | 0. |
| 23 | 95 | 75 | 85 | +10 | 20 | 0 | 0.00 | 0.0 | 0. |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 79 | 70 | 75 | +0 | 10 | 0 | 1.06 | 0.0 | 0. |
| 25 | 91 | 67 | 79 | +4 | 14 | 0 | 0.00 | 0.0 | 0. |
| 26 | 91 | 70 | 81 | +6 | 16 | 0 | 1.20 | 0.0 | 0. |
| 27 | 82 | 69 | 76 | +1 | 11 | 0 | 0.00 | 0.0 | 0. |
| 28 | 87 | 71 | 79 | +4 | 14 | 0 | 0.00 | 0.0 | 0. |
| 29 | 87 | 71 | 79 | +5 | 14 | 0 | .33 | 0.0 | 0. |
| 30 | 86 | 70 | 78 | +4 | 13 | 0 | .26 | 0.0 | 0. |
| 31 | 79 | 69 | 74 | +0 | 9 | 0 | .56 | 0.0 | 0. |
| TOTALS | | | | | 410 | 0 | 5.89 | 0.0 | |